NASA
TT
F-345
c.1

THE EARTH IN THE UNIVERSE

Edited by V. V. Fedynskii

TECH LIBRARY KAFB, NM
0068859
LOAN COPY: RETURN
AFWL (WLIL-2)
KIRTLAND AFB, N M

TRANSLATED FROM RUSSIAN

Published for the National Aeronautics and Space Administration, U.S.A.
and the National Science Foundation, Washington, D.C.
by the Israel Program for Scientific Translations

TECH LIBRARY KAFB, NM
0068859

Geographical Series
Geograficheskaya seriya

THE EARTH IN THE UNIVERSE

(Zemlya vo vselennoi)

Edited by V. V. Fedynskii

Editorial Board: I. Ya. Ballakh, A. L. Chizhevskii,
V. V. Piotrovskii, and N. I. Taranov

Izdatel'stvo Sotsial'no-ekonomicheskoi Literatury
"MYSL'"

Moskva 1964

Translated from Russian

Israel Program for Scientific Translations
Jerusalem 1968

NASA TT F-345
TT 66-51025

Published Pursuant to an Agreement with
THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
and
THE NATIONAL SCIENCE FOUNDATION, WASHINGTON, D.C.

Copyright © 1968
Israel Program for Scientific Translations, Ltd.
IPST Cat. No. 1419

Translated and Edited by IPST Staff

Printed in Jerusalem by S. Monson
Binding: Wiener Bindery Ltd., Jerusalem

Available from the
U.S. DEPARTMENT OF COMMERCE
Clearinghouse for Federal Scientific and Technical Information
Springfield, Va. 22151

/II/13/5

Table of Contents

INTRODUCTION 1

E. T. Faddeev. Some characteristic aspects of modern science 6

Part One
MATTER AND PHYSICAL FIELDS

D. D. Ivanenko. The structure of matter and attempts to create a unified theory of matter 21

Yu. S. Vladimirov. New developments in the study of gravitation 56

Part Two
STRUCTURE AND EVOLUTION OF THE UNIVERSE

V. A. Ambartsumyan. Galaxies and galactic evolution 62

B. A. Vorontsov-Vel'yaminov. Facts and puzzles concerning the structure of galaxies 80

V. S. Brezhnev. New ideas in cosmology and astrophysics 84

I. Ya. Ballakh. The role of explosive phenomena in cosmogonic processes . 88

S. S. Gamburg. Some regularities showing similarity of the solar and planetary systems 94

S. B. Pikel'ner. The evolution and dynamics of the Sun 104

V. V. Fedynskii. Some problems involving both the Earth sciences and space sciences. 113

Part Three
STRUCTURE AND EVOLUTION OF THE EARTH

B. L. Lichkov. Symmetry features of the Earth associated with the gravitational field, structural geology, and hydrogeology . . . 122

T. D. Reznichenko and S. D. Reznichenko. Some regularities in the evolution of the Earth 138

P. S. Veitsman. Deep seismic soundings and studies of the structure of the Earth's crust in the USSR 189

V. A. Tsaregradskii. Regular long-period variations in the velocity of the Earth's rotation and related deformations of the Earth's crust 194

G. F. Lungersgauzen. Periodic climatic variations in the Earth's geological past 212

V. V. Piotrovskii. Application of morphometry to studies of the Earth's relief and structure 228

G. G. Khizanashvili. Formation of submarine valleys in the light of the dynamics of the Earth's axis 244

S. Yu. Brodskaya. Paleomagnetic research in the USSR 258

V. B. Neiman. A comparative description of hypsographic data of some planets 264

Part Four
SOLAR ACTIVITY AND THE EARTH

V. V. Arsent'ev. Giant solar flares in 1961. 271

S. I. Isaev. On the existence of a region of enhanced auroral activity to the south of the zone of maximum auroral frequency 275

A. L. Chizhevskii. One aspect of the specific bioactive or Z-radiation of the Sun 280

A. L. Chizhevskii. Physicochemical reactions as indicators of cosmic phenomena 308

N. A. Shul'ts. Effect of variations in solar activity on the number of white blood cells 316

N. S. Shcherbinovskii. The rhythms of prolific breeding of organisms determined by cyclic solar activity. 331

Part Five
BIOSPHERE OF THE EARTH AND PHYSICAL FIELDS

M. S. Eigenson. Abundance of organic matter in the universe 345

A. L. Chizhevskii. Atmospheric electricity and life 348

B. D. Vasil'ev. Atmospheric air, life, and the blood 364

A. A. Peredel'skii. Penetrating radiations and radioecology 369

A. V. Krylov. Magnetotropism in plants 387

Part Six
HISTORY OF SCIENCE

A. L. Chizhevskii. K. E. Tsiolkovskii's world priority 394

LIST OF ABBREVIATIONS. 402

INTRODUCTION

The space age was initiated on 4 October 1957, when the first Soviet artificial satellite was launched. Then, between 1961 and 1963, Gagarin, Titov, Nikolaev, Popovich, Bykovskii, and Tereshkova made their heroic entering into space. As a consequence, the science of the Earth is now going into a new phase of reappraisal and vigorous development. The Earth viewed from interplanetary space, the application of the advances in physics and modern technology to the study of the Earth's deep interior and the remote fringes of the terrestrial atmosphere, the incorporation of new disciplines into the science of our planet—all these call for a fresh approach to many seemingly familiar phenomena.

This book presents a series of articles, covering a broad range of subjects, by a group of Soviet scientists writing on some of the problems of modern science, such as the structure of matter, the nature of physical fields, the formation and evolution of the Earth and the universe, solar activity and the Earth, and the interaction between the Earth's biosphere and physical fields. Some facts from the history of science which are related to the "cosmization" of natural science (the emergence of science into the reaches of outer space) are also presented. Many of the ideas expressed in the articles of this collection draw upon the works of great Russian scientists of the past, such as K. E. Tsiolkovskii and V. I. Vernadskii, whose topical interest has been revived with the onset of the space age.

E. T. Faddeev's article is a philosophical essay aiming to summarize the contemporary stage of development of science, which is at present going through a period of transition, and which has come to play a vital role in human affairs. This period of transition is characterized by the "cosmization" of science, which has provided man with the means of launching himself into space and mastering cosmic forces.

In Part One, "Matter and Physical Fields", the noted Soviet physicist D. D. Ivanenko presents in his article "The Structure of Matter and Attempts to Create a Unified Field Theory" a brief review of modern conceptions on the structure of matter and on the nature of physical fields. This article is presented with the article of Vladimirov, in which the author discusses the proceedings of the First Soviet Conference on Gravitation (1961) and dwells on the modern views on gravitation. Science is now striving to determine the link between the forces of universal attraction and the innermost properties of matter residing inside nucleons, and the article traces out the course of research in this field.

The structure and evolution of the universe are discussed in the articles of Part Two. This part of the book opens with an article by the eminent Soviet astrophysicist, Academician V. A. Ambartsumyan, who describes in a simple and lively style the fundamental facts which have

crystallized into what is known as extragalactic astronomy. This field comprises the study of the remotest regions of the universe, as far as the human eye, aided by modern powerful telescopes, can see. The investigation of these "limits" of the universe brings up enormously complex cosmological problems hinting at a general theory on the structure of cosmic space. A point of great interest is the description of the nonstationary processes that take place in the remote regions of the universe and indicate that the latter is in a continual state of development and transformation.

B.A. Vorontsov-Vel'yaminov points out in his article that some processes of this kind suggest the possible existence of unknown forces which relegate to the background the gravitational forces that are all-powerful in our region of the universe.

The problems of extragalactic astronomy were discussed at the meeting of the Commission on Cosmogony of the Astronomical Council of the USSR Academy of Sciences (1961). This aspect is treated by V. S. Brezhnev.

In I. Ya. Ballakh's article the idea is put forward that explosive (nonstationary) processes have played an important part in the formation and development of the solar system.

S. S. Gamburg describes an interesting similarity in the structure of the solar and planetary systems which, in the author's opinion, bespeaks the fact that these systems have been formed in stages. S. B. Pikel'ner gives an up-to-date account of the nuclear reactions considered to be the source of the Sun's radiation. He also discusses in his article the evolution of the Sun. Proceeding from some examples involving basic problems in geology, geophysics, geochemistry, and astronomy, V.V. Fedynskii points to the unexpected ways in which these sciences come into contact when projects of comprehensive study are contemplated.

Part Three, the longest in the collection, deals with the structure and development of the Earth. In his comprehensive article "The Symmetry of the Earth as Related to its Gravitational Field, Tectonics, and Hydrogeology", B. L. Lichkov examines the interaction between the variations in the rate of rotation of the Earth and the motions occurring in the terrestrial crust. The article underscores the unity of the three envelopes of the Earth (lithosphere, hydrosphere, and atmosphere), and it attributes the zonality of their structure to the action of centrifugal forces. Of special interest are the author's discussions on the formation of riverbeds and on subsurface drainage, conditioned by the processes under consideration. T. D. and S. D. Reznichenko have written a substantial article analyzing the connection between the diurnal rotation of the Earth and tectonic and climatic processes. The authors have some original ideas concerning the transport of sedimentary rocks by rivers, which they interpret as a process counteracting the concurrent variations in the rate of rotation of the Earth. The article presents a novel view on the course of events in the Quaternary period, which will no doubt prove most interesting.

Deep seismic sounding constitutes at present the most effective method for studying the structure of the terrestrial crust and the upper mantle of the Earth. Soviet scientific achievements in this field are described by P. S. Veitsman, in an article giving a résumé of the findings of the Conference on Deep Seismic Sounding convened by the Academy of Sciences of the USSR in 1960.

V.A. Tsaregradskii writes an interesting article in which he sustains the viewpoint of investigators who claim that the variations in the rate of rotation of the Earth constitute one of the main causative factors of tectonic processes. The author considers that the rate of rotation of the Earth is regulated by the position of the solar system in the Galaxy. Since the Sun has a period of revolution about the galactic center of about 170 million years, it follows that the orogenic cycles and other geological events in the life of our planet should recur with the same periodicity. The same viewpoint is adopted by G.F. Lungersgauzen, in his consideration of the periodic variation of the Earth's climate in the geological past. In Lungersgauzen's opinion, the long-term variations in the climate which depend on the position of the Sun in the Galaxy can be attributed to the absorption of sunlight in the dust matter concentrated in a thin layer near the galactic plane.

V.V. Piotrovskii points out the recurrent pattern that may be observed in the morphological features of the Earth's surface, in the structure of the Earth's crust, and even in all three envelopes of the planet. According to the author, the simple mathematical relationships which describe this repeating pattern reflect an objective fact and deserve further study.

G.G. Khizanashvili discusses in his article the formation of submarine troughs, resulting from the fluctuations in the level of the World Ocean and climatic conditions. The zone most favorable for the formation of submarine troughs is thus found to be confined between the latitudes of 32 and 50°, which is indeed borne out by observation.

Many advances have recently been made in paleomagnetic research. The findings of these investigations were presented at the Fourth All-Union Conference on Paleomagnetism, of which an account is given in the article by S. Yu. Brodskaya. V.B. Neiman draws up some hypothetical hypsographic curves to describe the distribution of heights and depths on Mars and Venus, proceeding from available data on these curves for the Earth and, in part, for the Moon.

Part Four, entitled "Solar Activity and the Earth", deals with some new and important questions. The article of V.V. Arsent'ev and S.I. Isaev introduces the subject. It is explained that our Sun is a weakly variable star with a principal period of 11.1 years. In years of peak solar activity, tremendous chromospheric flares in the ultra-violet and X-ray portions of the solar spectrum produce streams of solar corpuscles of a density of 10^{10} - 10^{11} per cm^3 and a velocity of about 1000 km/sec, which have a powerful effect not only on the electrical and magnetic life of the Earth but also on its biosphere. Prof. A.L. Chizhevskii and those who followed up his work in the USSR (G.A. Ivashentsev, A.A. Sadov, S.T. Vel'khover, G.D. Belonovskii, and some others) and abroad (M. Tanon, R.J. Dubos, M. Faure, J. Sardou, M. Takata, T. Murazugi, S. Takata, M. Laignel-Lavastine, T. Düll and B. Düll, H. Berg, and some others) devoted much effort to the study of this interesting realm of phenomena. In 1939 the First International Congress of Biophysics and Biocosmics was held in New York, at which the honorary presidents were Prof. A.L. Chizhevskii from the USSR, and Profs. Paul Langevin and Arsène d'Arsonval from France. The two articles by Prof. Chizhevskii, devoted to the subjects of space biology, space epidemiology, and space medicine, give an account of these new disciplines, which were founded in the USSR more than forty years ago. These articles show how valuable these disciplines can be in modern medicine, as was proved by the recent notable investigations of the Italian

scientist Prof. G. Piccardi and by a large group of scientists in various countries in Europe, Asia, and Africa.

Chizhevskii's studies of the relation between space phenomena and physiological effects (infections, strokes, infarctions, sudden death, etc.) are paving the way for electronic medicine (as it was named by K. E. Tsiolkovskii) and reveal new fields of application for medical practice (such as the prophylactic drug treatment and "screening" of patients underground, on the basis of heliophysical data).

Credit should be given to People's Commissar of Public Health Prof. N. A. Semashko, under whose editorship the above works appeared in print, and to the foresight of K. E. Tsiolkovskii, who wrote a paper on that subject published in 1924.

Dr. N. A. Shul'ts discusses the effect of chromospheric flares on hemogenesis, i.e., on the mass increase or decrease of white blood cells in man all over the globe. N. S. Shcherbinovskii, Corresponding Member of VASKhNIL, gives an account of his investigations on the periodicity in the mass reproduction of a redoubtable pest, the locust, in the Asiatic countries and the southeast of the Soviet Union. This work is also of considerable practical value.

Part Five presents a study of the biosphere of the Earth and the way it is affected by physical fields. This section opens with a very interesting article by the eminent Soviet astronomer, the late M. S. Eigenson. The main point of the article is that interplanetary space is pervaded with the raw material necessary for the genesis of organic life. This apparently paradoxical idea is supported by convincing evidence, whose significance is stressed by the author.

In the next article, Prof. Chizhevskii gives an account of his well-known investigations, taking place over forty years, on the effect of the carriers of atmospheric electricity—the airborne negative oxygen ions—on the organism of animals and man. He clearly shows the great importance of artificially produced negative air ions in everyday life and in the prophylaxis and therapy of many serious diseases. Particularly significant are Prof. Chizhevskii's studies on the effect of deionized air (i.e., air completely deprived of its ions) on animals. Normal, natural air, from which all the ions have been removed does not sustain life and the animals die. When studying in the thirties the ways in which air ions affect human beings, Chizhevskii felt it was necessary to investigate some of the geometrical, electrical and magnetic properties of the blood. This topic is treated by B. D. Vasil'ev, Candidate of Medical Sciences, in the article "Atmospheric Air, Life and the Blood". This article demonstrates the strong bond that links together the system "air–blood".

The article by A. A. Peredel'skii, Doctor of Biological Sciences, deals with some aspects of penetrating radiation and radioecology. The author is an eminent authority on radioecology. The article deals with a broad range of problems—from the impact of cosmic sources of background radiation on organisms to the practical importance of radioecology for the decontamination of land and water bodies. The author describes the pattern of distribution and translocation of radioactive wastes produced by natural biological and abiological processes and activities. The article demonstrates the importance of radioecology in the study of the effects of radioactive wastes and in developing effective ways of eliminating health hazards. Methods are given for the disposal of the wastes and the possibility is appraised of "steering" the phenomena in question.

Lastly, the article by the late botanist A.V. Krylov, Candidate of Biological Sciences, deals with magnetotropism in plants. Actually, the effect of a magnetic field on bioprocesses has been a moot point for a long time, and many scientists denied its possibility altogether. However, in 1951, a paper was published to the effect that the erythrocytes moving in the bloodstream exhibit a magnetic field (Chizhevskii). Independently, A.V. Krylov conducted experiments showing that the roots of plants grow along the lines of force of the Earth's magnetic field. In recent times, many authors have detected a reaction to a magnetic field in several specimens of animal life. Consequently, biology and geophysics find themselves linked together in a novel way.

The last portion of the book, Part Six, highlights some points in the history of science which fittingly display the trend toward the cosmization of natural science. In a brief personal account, Chizhevskii recalls the struggle for world recognition of the contribution of K.E. Tsiolkovskii, in which he came to be involved in his youth.

It is hoped that the body of ideas presented in this collection will impel the reader to seek further knowledge on the topical issues of natural science bearing on the relationship between the Earth and the boundless universe around it.

E. T. Faddeev

SOME CHARACTERISTIC ASPECTS OF MODERN SCIENCE
(An essay in philosophical analysis)

We are witnessing in our time an unprecedented interest in the investigation of the position of science in social life and its rapidly growing importance in human progress. Philosophers, naturalists, sociologists and writers of many countries have contributed to this subject a considerable number of articles, pamphlets, and substantial monographs. Nevertheless, the study of science and of the multifarious ways in which it is connected with other social processes is actually just beginning.

We cannot rest content with this situation. Under the communist system, where science is becoming a direct productive force, the investigation of the processes of scientific inquiry is of particular importance—not only from the theoretical but especially from the practical standpoint. It becomes imperative to understand fully the process of scientific development in order to derive the full benefit of rational long-range planning in the national economy, in education, and in the ideological realm, and in order to promote scientific and technological progress.

How can a radical solution of these problems be achieved? We will not attempt a full answer to this question, but only comment on a fact of particular import in the contemporary state of affairs. Inasmuch as science itself is becoming the object of scientific investigation, it is natural that definite attitudes and methods of approach should have developed. These attitudes and methods have proved to be inadequate, however. In order to achieve results in determining the new traits and tendencies of scientific progress, the need arises for new ideas and outlooks which go beyond the traditional conceptions. It is here that, in our view, it can prove most fruitful to apply to the theory of science (natural science included) the propositions of Marx and Engels on the prehistory and history of mankind.

The founders of Marxism introduced into sociology the concept of the socioeconomic structure and considered the historical process as a succession of such structures, placing social evolution in a broader context. The period from the inception of the first human community in the distant primitive ages to the construction of world communism constitutes, according to Marx and Engels, simply a prelude to true history, a prehistorical hiatus. This period constitutes, fundamentally, a transition from the biological to the social, a maturing of society into a new form of motion of matter, and a passing of the world into a new stage of evolution. The victory of the communist system announces the end of the prehistory and the beginning of the true history of mankind, which will rid itself forever of the remnants of animal behavior and will find stable forms of social organization. Thus, the revolutionary movement from capitalism to communism does not merely

mean that one structure is replaced by another of a higher order, but also implies a much more profound and sublime change.

In working out their thesis on prehistory and history, Marx and Engels proposed a number of criteria by means of which these periods can be distinguished. Before communism, society evolves in a spontaneous manner. In communist times, people consciously, and thus with increasing success, control this process. Prehistory is the domain where stark necessity rules, where man's productivity is governed by need. The emergence into history constitutes the step into freedom, where people will have maximum leisure and opportunity to cultivate their natural gifts, and where the development of man's potentialities will be an end in itself. These criteria certainly require further elaboration. But something else is of interest to us: the universality of the distinctive traits characterizing pre-communist and communist times. Each of these traits manifests itself throughout the period to which it belongs, i.e., throughout prehistory, or history.

We can assume that there are actually many more criteria for distinguishing between prehistory and history than we can cite at present. In this respect, new discoveries are yet to be made. However, the distinctive features of each of these periods that are known to us, as well as those still unknown, must indubitably leave their mark, exerting an influence in all walks of social life. That is to say, if any social phenomenon is common to both pre-communist and communist times, its prehistorical aspect will be intrinsically different from its historical one.

Clearly, this rule also holds good for science. Granting this, it can be expected that science in historical times will present characteristics distinct from those of science in pre-communist society. These characteristics are already beginning to take shape and to have a growing effect on the specific features of scientific progress, as the movement from prehistory to history is in full swing. It thus follows that if we are to study the specific features and regularities of contemporary natural science, we cannot abstract ourselves from these processes. On the contrary, we must place them at the forefront of our investigations. In parallel to the history and prehistory in the evolution of society as a whole, it is necessary to distinguish between the prehistory and true history of science, a social phenomenon. This will provide new clues for the proper interpretation of the present-day trends in the development of scientific thought, experimentation, and organization.

It is possible to mention quite a number of features of science which are perceptibly changing as the time of true history draws closer. Thus, for instance, until recently, the various branches of natural science (as well as the individual scientific disciplines within them) were tenuously or not at all connected. Nowadays, we can see a rapprochement between different sciences, sometimes quite removed from each other. These interpenetrate and new "hybrid" sciences are created at the boundaries where two or several old ones meet. This is quite a marked tendency, which permits us to conclude that scientific enquiry is ripening into a synthesizing, comprehensive, and highly dynamic approach to the study of nature. The same marked tendencies are noted in the transformation of science into a direct productive force, the industrialization of natural science, the multiplying uses of mathematics and cybernetics, etc. Each one of these particular features deserves investigation by large scientific teams, and obviously exceeds by far the scope of a single article.

We will dwell on one particular process, which may be referred to as the cosmization of science, i.e., the transition from a purely terrestrial view of nature to a cosmic outlook. Analysis shows that this may be one of the major developments of scientific knowledge as society proceeds from prehistory into history. The emergence of natural science into the cosmic age of its existence is a dominant tendency, which has an effect (direct or mediated) on all the characteristics of contemporary scientific progress. The cosmization of scientific knowledge is a relatively recent development.

At its inception, in antiquity, in the Middle Ages and to a certain extent in modern times, science was geocentric. Its approach to the study of the phenomena and laws of nature, its methods of investigation, indeed its very interpretation of the initial propositions and end results were primarily terrestrial. Matters pertaining to the heavens, to the "universe at large", were mainly the occupation of philosophers. Ideas about cosmic processes and their possible influence on terrestrial occurrences were purely speculative. Science was primarily concerned with terrestrial things and was earth-bound. This geocentricity of science was vividly embodied in the Aristotelian teachings, concerning the two pairs of opposing "primary qualities" and the four elements (earth, water, air, fire) on which all of observable reality was based.

It is true that the old science did not present an unrelieved geocentric landscape. The most notable exception was, of course, astronomy, whose eyes were turned toward the heavens. However, the cosmic content of astronomical science was quite limited in scope. Astronomy was fettered by terrestrial concepts, which obscured from view the true nature of its observations, as its theoretical basis was geocentrism interwoven with anthropocentrism. This science finally crystallized into the Ptolemaic system; the cosmos was not viewed as such, but was seen through terrestrial eyes. These ideas were accepted as the truth and no alternative was recognized. The heliocentric system of Aristarchus of Samos was considered heresy, for it contradicted everyday (i.e., "purely terrestrial") experience.

Another exception was, in a certain measure, mathematics. Being the most abstract of the sciences, it quite early derived generally valid propositions. The multiplication table is just as true in the Andromeda Nebula and in the innumerable other parts of the universe as it is on Earth. Although mathematical deductions and rules were based on terrestrial data, their essence went beyond the confines of the Earth, unlike the other, earthbound branches of science. However, the cosmic character (in the above sense) of mathematical thought was not realized even by its very representatives and creators (barring some philosophical speculations). Most important: the cosmic aspect was never explicitly stated in mathematics. This science never studied the quantitative properties of an actually given cosmic infinity, that is, it did not give any representation of the universe defined as an infinite entity.

Of course, the concept of infinity gradually made its way into mathematics. The problem of the infinitesimal was posed as far back as the time of the ancient Greeks. However, the first real progress in this direction occurred when the differential and integral calculus were created. Significantly enough, it was not until the concept of an infinitely great quantity was formulated (in the 17th century) that the first step toward the mathematical study of the universe was made.

The science of prehistorical time was thus above all a terrestrial science, even taking into consideration some individual exceptions (which did not go very far at any rate). Engels had good grounds for writing in his "Dialectics of Nature" that: "All of our official physics, chemistry, and biology are exclusively geocentric, designed solely for the Earth."

In the natural science of modern times, however, new, cosmic trends sprouted forth from the terrestrial groundwork, notably, as was to be expected, in astronomy and mathematics. The achievement of Copernicus, continued by Giordano Bruno and Galilei, announced the definite cleavage of astronomical science from its terrestrial bondage. And though the change in outlook involved only the solar system, while everything that lay beyond was still regarded as a sphere of motionless stars, the Copernican system truly constituted a revolution, imparting the first serious blow to the geocentrism which had pervaded natural science up till then.

The discovery of spectral analysis led to other advances toward the proper knowledge of the universe. Until then astronomy had been chiefly based on classical mechanics*; from that point onward, the whole complex of astronomical science underwent a thoroughgoing refashioning on the basis of astrophysics. This complex was thus substantially supplemented by newly developed astrophysical or related disciplines.

It may be said that the introduction of astrophysical methods and concepts (of a distinctly non-terrestrial character) brought about a rebirth of astronomy. This new, essentially astrophysical astronomy differs from the old, classical one mainly in its having renounced the intrinsically terrestrial standpoint in the study of the cosmos.

Progress in the astronomical sciences has since proceeded at an accelerated pace, especially in astrophysics, which has come to be increasingly relied upon in the investigation of the regions around the Sun and in the study of galactic and extragalactic space. A new stage was reached with the advent and rapid development of radioastronomy (together with its offshoot, radar astronomy). This technique has been a powerful tool for probing into cosmic processes and making new discoveries, and has considerably expanded the portion of the universe accessible to observation.

Thus, since the time of Copernicus, astronomy has firmly set out on the way to becoming a truly cosmic science, with its sights free from terrestrial fog. The end of the 19th century and the first half of the 20th century have witnessed spectacular advances, both qualitative and quantitative, in the astronomical sciences. The line of development traced above constitutes the first fundamental trend toward the cosmization of natural science.

Following astronomy came mathematics. Aside from a few preceding efforts of little significance, the turn toward the cosmos was signaled by the creation of Lobachevskian geometry. Its cosmic character was perceived (at least in part) by the author himself. The strange content and results of the new geometry resulted from a definite cause. The mathematics involved dealt with properties of space that become manifest only over extensive portions of the universe and are "not visible" on a terrestrial scale.

Of course, the non-Euclidean geometry of Lobachevskii just laid out a new domain of mathematical interest. This initial venture was soon followed

* J.D. Bernal: "... The greatest triumph of science of the 17th century was doubtlessly the completion of a general system of mechanics, capable of explaining the motion of the stars in terms of the behavior of matter observed on the Earth" (emphasis mine — E.F.).

by other signs indicating—under a most original guise—a gradual transition of the mathematical sciences to a cosmic orientation. In the seventies of the last century, G. Cantor formulated the basic propositions of the theory of sets, whose main concern is the investigation of infinite sets. The contradictions of mathematical infinity, and certain of its paradoxical properties (for instance, in the arithmetic of transfinite numbers), are a reflection of the actual contradictions and properties involved in the real infinity of the universe. Perhaps the most noteworthy thing about the theory of sets is the fact that it has not only evolved quite rapidly but also impinged upon literally all the main branches of mathematics. Set-theoretical axiomatics gained increased importance in arithmetic, geometry, the theory of probability, and mathematical logic. Many important new mathematical disciplines, such as the theory of functions of a real variable, general topology, to mention but a few, could not be made possible without the theory of sets. Whereas at first mathematics proceeded from the particular and finite to the infinite, now the finite itself is interpreted from the standpoint of the infinite, and thus the general validity of mathematics becomes richer in implications than was the case with the older mathematics.

However, mathematical science was not the only one to exhibit a cosmic slant. At the turn of the 20th century, many branches of natural science started, one after the other, to contemplate their subject of study in its cosmic aspect. The cosmic outlook broke in full force upon physics, when Einstein formulated the special, and later the general, theory of relativity, which nowadays constitutes the theoretical foundation of the principal domains of the new, nonclassical physics. This theory, as is known, is concerned with super-high, truly cosmic velocities, and in general, with many processes which occur mainly (or which are most detectable) not under specifically terrestrial conditions but in the wide expanses of the universe (which include our planet as well). But matters do not end with Einstein's discoveries. Across the span of half a century, there has been the formation of atomic and nuclear physics, cosmic-ray physics, plasma physics, vacuum physics, cryophysics, etc. Each of these disciplines investigates either specifically cosmic processes, or phenomena produced by cosmic factors, or else some terrestrial occurrences considered as a special instance of cosmic phenomena. In view of the multiplication of such specialized departments in physics and of the preponderance they are gaining, it becomes clear that physics as a whole is being transformed into a cosmic science.

The same may be observed, though to a lesser extent, in the other branches of natural science of the first half of the century. The cosmic element in one form or another is making its way into chemistry, biology, geology, and geography. Chemistry, for example, now includes radiation chemistry and cryochemistry, and research has been initiated in the chemistry of super-high temperatures (in particular, where this is directly related to the development of rocket fuels and engines) and on the effect of cosmic factors on chemical reactions and the chemical properties of substances. Geology and geography (and even meteorology)—these most terrestrial of all branches of natural science—tend to consider their problems more and more from an extraterrestrial standpoint, or as related with cosmic aspects, and to treat the Earth as one of the planets, i.e., as

a cosmic body. These changes are even more pronounced in geophysics, which was born, to begin with, under the sign of the cosmos.

On the basis of the foregoing we can deduce a second trend toward the cosmization of natural science. This trend involves the expansion in the last century (to say nothing of the present one) of the object of study of many of the old classical sciences, and the emergence from the framework of purely terrestrial phenomena and processes, with an interest in the cosmic aspects of research.

But this is not all. A notable advance occurred in the development of natural science of the last decades, brought about by the creation of new, primarily cosmic, scientific disciplines, chiefly concerned with the study of cosmic objects. After the inception of astrophysics at the end of the 19th century, the beginning of our century was marked by the appearance of theoretical astronautics. This event dates from 1903, when K.E. Tsiolkovskii's celebrated work "Issledovanie mirovykh prostranstv reaktivnymi priborami" (The Exploration of Outer Space by Means of Reaction Devices) was published. Later to develop were the elements of astrobiology and in particular of astrobotany, and the fundamentals of space chemistry. Toward the 50's of this century, the science of aeronomy was founded, as well as astrogeography and astrogeology. Aviation medicine was also developed, the direct forerunner of space medicine.

Admittedly, it is rather arbitrary to call most of these sciences in their initial form cosmic, or "purely" space sciences. Astrogeography and astrogeology, for instance, are as yet ordinary geography and geology carried over into space and constitute to a large extent a generalization from the appropriate terrestrial data to cosmic data (the particular case of astrogeology basically takes into account cosmic factors in the geology of the Earth). But such will not always be the case. Sooner or later, quantity will change into quality. The direct geographical and geological study of other planets and planetlike bodies will not only uncover new facts and lead to a deeper understanding of familiar laws but will also call for a reappraisal of our knowledge of ordinary terrestrial geography and geology. We shall have occasion to come back to this point. Obviously, at present astrogeography and astrogeology may be classified as cosmic sciences in potential only. On the other hand, astrophysics, astronautics, or astrochemistry started out as primarily space sciences (the extension of any particular data to space is in the present case of secondary importance); they have a "direct" approach to their cosmic objectives.

Actually, the changes occurring in science in the process of its cosmization defy classification due to their complexity. All the same, we must by no means dismiss the possibility of gaining some insight from them. To sum up, we note an additional new significant trend toward the cosmization of natural science, which has appeared in the last 100 years and taken shape in the gradual formation of various space sciences (pertaining to space either directly or by implication).

The three trends mentioned above (i.e., the transformation of astronomy into a truly cosmic science, the penetration of cosmic subjects into classical and modern science, and the appearance of "purely" cosmic scientific disciplines) could be expected to contribute toward a fourth trend, as indeed they have. This trend has been an increasingly closer association and even an interweaving of the astronomical discipline with the other branches of natural science, a convergence of the whole complex of astronomical

science with the other scientific fields. Back in 1932, Academician V.I. Vernadskii made the prophetic statement that "atomic physics and chemistry have unexpectedly proved of fundamental importance in cosmic and cosmogonic processes". On the other hand, as J.D. Bernal has written: "astrophysics and cosmology ... are beginning to impinge on the very core of high-energy physics, and if the potentialities of the Earth are to be fully exploited ... these sciences will undoubtedly have to be applied in geophysics and geochemistry". Likewise, it is a familiar fact that astrophysics, cosmogony, and the physics of the "elementary" particles are intimately linked; there are cases when it is hard to tell where particle physics ends and astronomy begins.

Since natural science has turned toward space over an ever-increasing range of subjects—from mathematics and mechanics to biology and medicine —a demand has been created for new tools of investigation, which would provide the means of studying directly cosmic objects, phenomena, and processes. The indirect techniques, while basically retaining their value, were no longer accurate or comprehensive enough to keep up with the advances in space science (and thus in terrestrial science as well, which is, in the last analysis, only a specialized branch of cosmic science). In other words, after science had launched itself into space, its creator, man himself, was bound to follow. Since scientists have begun to ask new questions, the need for new answers has arisen accordingly. These answers can be supplied by applied astronautics, which offers scientists the possibility of carrying out research directly in space.

Thus, the way to the launching of the first satellites and space rockets was paved by the whole development of natural science, and primarily by its space orientation (the social aspect is not considered here). At the same time the appearance of applied astronautics denotes a highly significant qualitative jump in scientific progress and marks a definite frontier in the history of science. The advances of science toward space noted up to this frontier may be considered only as some preliminary or preparatory stage. With the emergence of scientific instruments, as well as the researcher himself, into space came an intensive process of cosmization of the whole body of science, which is now proceeding at an accelerated pace. A direct transition is under way, from the predominantly geocentric natural science of prehistory toward the cosmic natural science of the future, i.e., toward the science of the period of true history of mankind. We are, of course, just standing at the beginning of all this and we still have a long way to go. But the fact that we are moving in this direction is obvious from the way things are going at present. During the short time since 4 October 1957, the basic trend toward the cosmization of natural science has not only rapidly evolved and led to considerable achievements, but has even become one of the significant features of modern science. In the course of a few years more ground has been covered than during all of the last century.

The complex of astronomical sciences is also in the process of rapid evolution and qualitative transformation. Applied astronautics has already led to the creation and quick development of far-ultraviolet and gamma-ray astronomy, which would not be possible without launching scientific instruments into space. Neutrino astronomy has also become a subject of topical interest. Further extensive developments are expected in phototelevision investigations, whose first spectacular achievement was the photographing

of the reverse side of the Moon. The launching of basic equipment of optical and radio astronomy into space will give a fresh impetus to all the main astronomical sciences. The first artificial satellites of the celestial bodies, and particularly automatic stations on their surfaces, will (many scientists hope) result in a whole series of new astronomical fields, or new departments within already existing sciences, such as selenophysics, selenology, selenochemistry, areophysics, areology, areochemistry, etc.

The cosmic aspect, that is to say the body of problems bearing on space, is now making inroads into every single science, both old and new, theoretical and applied. This is especially brought about by the fact that natural science is being faced with the multiplying problems raised by astronautics and has to "put itself to work" on them. Thus it is not mere chance that such "cosmized" sciences as radiation chemistry, radiation physics of the solid state, radiation metallurgy, radiation genetics, radiobiology, etc., are advancing by leaps and bounds. These sciences help to study the effect of radiation in space on various chemical substances, on structural and other materials, on heredity, and on the organism in general.

The number of new "purely" cosmic sciences is steadily growing. In addition to the ones preceding the creation of applied astronautics, recent years have seen the appearance of space biochemistry, space microbiology, space genetics, space medicine, space physiology, space physiology of higher nervous activity, space psychology, etc. One could also say that planetary physics has made its appearance (with the reservations we mentioned before with respect to astrogeography and astrogeology), in view of the fact that experiments have been conducted in which the Moon was found to have no detectable magnetic field, and similar experiments are under way for other heavenly bodies. It may be expected that with further advances in the conquest of outer space research will be started in space crystallochemistry, astrometeorology, etc. It is possible that intrinsically new phenomena and processes will be discovered in space, leading to unsuspected developments and unfamiliar specialized branches of science. It is furthermore obvious that both the youngest and the older space sciences are bound to benefit tremendously from the accumulation of factual material drawn directly from extraterrestrial sources. There is no doubt that the new space sciences will soon gain momentum and reach the same degree of sophistication as the older, well-established classical sciences.

There is also a rapid interpenetration of astronomy and the other natural sciences. New specializations are making their appearance, such as nuclear astrophysics, i.e., a particular blend of nuclear physics and stellar astronomy. On the other hand, it is hard to imagine nowadays a physics which does not comprise astrophysics, geology, planetary cosmogony, meteorology, etc. The astronomical sciences are becoming increasingly interwoven with the remaining body of natural science, especially in the aforementioned subjects: selenophysics, selenochemistry, areophysics, etc. The division into astronomy and other natural sciences would not properly apply to these disciplines (or subjects), because these branches combine both astronomical and nonastronomical aspects. Thus, for instance, selenophysical or areological investigations, however they might be called or classified at present or eventually, will come to be conducted less and less by purely astronomical means and more and more by means of astronautics, primarily via human observers directly on the surfaces of heavenly bodies or near them.

To sum up, we conclude that modern natural science is leaving behind its geocentric past and emerging into cosmic space.

The conversion of the different sciences and of the whole body of natural science to space sciences takes a variety of forms. A case in point is that of biology. For the time being the latter basically remains a terrestrial science. However, the premises and factors orienting biology toward space are increasing in number and growing more and more effective.

One of the first indications of this was the appearance of astrobiology as a theoretical discipline at the beginning of this century. Its subject matter consists of the theoretical analysis of the possibility of life on any given heavenly body (or class of bodies), proceeding from what is currently known on the type of environment necessary to sustain life and on the physical conditions existing on specific astronomical objects. Almost no direct astrobiological observations, and certainly no controlled experiments, have been carried out in this field (barring some astrobotanical works by G. A. Tikhov and some others, and the work recently done on "astrobiological simulation"). At this point, astrobiology obviously draws upon terrestrial biology to a much larger extent than it contributes to it. It would be fair to say that theoretical astrobiology has sprung up from a terrestrial background and is still much too dependent on it to exert any appreciable reciprocal effect on the complex of ordinary biological sciences.

However, the situation is now beginning to change. Space biology, which has been made possible by the advances in applied astronautics, is probably going to exert a tremendous modifying influence on terrestrial biology. Space biology can solve experimentally the problems involved in maintaining terrestrial life forms in an environment of space flight and under extraterrestrial conditions in general. Moreover, it can ascertain the existence and the characteristics of life in outer space and on the celestial bodies of the solar system. It is eventually bound to deal with the problem of biological adaptation of extraterrestrial organisms to terrestrial conditions. The information gained in this scientific field will no doubt come to have an increasingly strong influence on many general and particular, theoretical and practical, concepts of ordinary biology.

Of course, the new space biology does not supersede or supplant the theoretical astrobiology that was produced much earlier. These are two distinct disciplines which remain mutually related in many complex ways (ways as yet unexplained and undifferentiated one from another). *

In the not too distant future, these two disciplines will probably be embodied into some unified astrobiological science, of which they will form organic parts. This astrobiology of the future will exert an increasing influence on the terrestrial life sciences, so that terrestrial biology will find itself being converted into a space science, from the inside, so to speak. At this point we have to mention a third significant factor setting a spaceward trend in biology, which also made its appearance at the beginning of this century.

At that time some ideas were held in scientific circles to the effect that biological phenomena occurring on the Earth were affected to a considerable

* By way of illustration we may mention the terminological debates and the differences of opinion as to whether it is astrobiology or space biology which is the more comprehensive of the two. The various views are expressed in an interesting paper by Zhukov-Verezhnikov, N. N., V. I. Yakovlev, and I. N. Maiskii. O teoreticheskikh problemakh kosmicheskoi biologii (Theoretical Problems of Space Biology).—Voprosy filosofii, No. 9. 1960.

extent by cosmic processes, chiefly by those associated with solar activity. One of the first to have set forth this concept was Prof. A. L. Chizhevskii, who undertook in 1915 a study of the effects of cosmic and some solar radiations on microorganisms and the growth of living tissues. In 1926-1927 he demonstrated the influence of solar eruptions on the functional state of the nervous system. Prof. Chizhevskii (whose work was largely ignored for a long time) was essentially the founder of some individual disciplines which have now become parts of the science which is generally known as agricultural and medical bioclimatology (or biometeorology). This science is devoted, specifically, to the study of the effect of cosmic factors on plant, animal, and human organisms, and is at present rapidly evolving. Its relative importance is steadily growing, especially since it is intrinsically connected with modern space biology.

All the events outlined above (even omitting some other basic factors) lead to one specific fact: the entire body of the biological sciences—both the purely astrobiological as well as the terrestrial—is manifestly becoming space-orientated. Instead of a narrow, terrestrial, geocentric viewpoint, it is now adopting a cosmic interpretation of the process of life and the laws governing it. "The study of the life forms which may have possibly originated on other planets", writes B.V. Kukarkin, "will probably prove a turning point in all our conceptions of the problem of life itself, its origin and development" (emphasis mine—E.F.). A revolution of this kind is bound to take place in biology, brought about by the joint action of all the above-mentioned "space-orientating causes".

Our brief survey of the basic trends and features in the space-orientation process of natural science would be incomplete if we were to confine the discussion to theoretical science only. Experimental techniques are also becoming space-orientated, and this aspect should be at least briefly considered.

Experiments performed in widely divergent scientific fields increasingly tend to display a cosmic slant, even though they are carried out on Earth under terrestrial conditions. Thus, for instance, Michelson's experiment (1881), as well as the numerous modified versions of it (up to the present), had the object of measuring the effect of the motion of our planet (considered as a cosmic body) on the velocity of light. This is clearly an unusual kind of experiment, both in its aim and in its method of approach. The same applies to the experiments with cosmic rays, which were started decades ago and are being carried out even now in surface and underground labs, as well as in the atmosphere. The number of such experiments, where cosmic factors or the phenomena produced by them are dealt with on Earth, is growing at a high rate. This tendency shows no signs of declining, despite the fact that the possibility now exists of conducting experimental work directly in space.

The second important trend in the space-orientation of scientific experiment, which also began manifesting itself some decades ago, involves the artificial re-creation, or at least simulation, of cosmic phenomena, processes, conditions, and factors (or some of their components). Thus, for instance, the bulk of experiments done in nuclear physics and the physics of elementary particles consists essentially of artificially reproducing those interactions of nucleons and other objects of the microcosm that usually take place under extraterrestrial conditions or occur on our planet (or near it) under the effect of cosmic factors and are intimately linked with them. Such

is also the case with experiments dealing with nuclear reactions, the "synthesis" of transuranic elements, the problem of a controlled thermonuclear reaction, etc. Unquestionably "space-orientated" are the experiments involving ultrahigh and extremely low temperatures which are characteristic of outer space, vacuum experiments, and experiments with various types of high-energy radiation. This is also true of the modeling of lunar rock formations, the simulation of a given set of space conditions in order to study the way in which plants and animals adapt to them, and the testing of artificial satellites and space instrumentation. Only three-quarters of a century ago such experiments were inconceivable. At the present time, however, they are assuming an ever-increasing importance in the general body of experimental work being done, and this despite the potential feasibility of carrying out many of these investigations directly in outer space.

Another space-orientated trend has made its appearance recently in experimental science, almost together with applied astronautics, involving the global character of certain experiments, covering in one way or another all the terrestrial globe or at least a major portion of it. For example, when developing the equipment for the production of artificial comets, Soviet scientists obtained in 1958 a cloud of sodium vapor at an altitude of 400 km. Its apparent size extended to the outmost stars of Ursa Major and it was visible from an area of several million square kilometers. Of course, tremendous possibilities for conducting experiments on a global scale have been uncovered by applied astronautics. Suffice it to mention in this respect the work being carried out, or being planned, on drawing up charts of the Earth's cloud cover, on continuous sounding of the ionosphere using radio waves, on the determination of the density and other properties of the upper atmosphere, on the study of the Earth's gravitational field, etc.

Finally, the fourth trend in the space-orientation of scientific experiment is toward the expansion of the experimental stage into space, far beyond the Earth. The radar echo bounced off the Moon in 1946 constituted in this sense a cosmic experiment, which marked the appearance of radar astronomy, a necessarily experimental science. A period of on-the-spot space experimentation has begun, and many experiments are beginning to assume truly cosmic proportions. The launching of each artificial satellite or space rocket is an example of a cosmic experiment. The production of artificial comets, the photographing of the far side of the Moon, and any forthcoming achievements of the same kind may be also classified as such. Accordingly, astronomy itself, which has traditionally been up till now an observational science, is turning into an experimental science. A branch of it, namely celestial mechanics, is also becoming an experimental discipline, for the launching of any spacecraft involves the practical application of the laws of celestial mechanics. Far-ultraviolet and gamma-ray astronomy are based almost entirely on cosmic experimental data. Experimental cosmology has got under way, with experiments involving the direct analysis of cosmic radiation away from the Earth and of interplanetary gas, etc. To all these must be added the constantly expanding assortment of a wide variety of cosmic experiments: geophysical, astrophysical, medico-biological, genetic, psychological, technological, etc.

There is no doubt that cosmic experiments in their various forms will come to play a leading role in science. Completely new experimental

domains are bound to appear and within a fairly short time. For instance, stress will be probably be laid on experiments involving the study and use of new rocks, minerals, and other raw materials on the Moon and the planets of the solar system. There are prospects for experiments involving the investigation of as yet unknown states of matter and substances which may be discovered in outer space. A true revolution will be wrought in biology by experiments on the adaptation of terrestrial microorganisms, plants, and animals to the conditions prevailing in outer space and on celestial bodies, on the adaptation of extraterrestrial life forms to terrestrial conditions, and involving the controlled changes made by man on the flora and fauna of other worlds.

Now, after all the foregoing, we have grounds for asserting that modern natural science is in fact on its way into space. Thus, the following question arises: where does this way lead? In other words, if science is now taking leave of the geocentric bias of the prehistorical period, what course is it going to take with the onset of the true history of mankind? Obviously, toward an intrinsically cosmic outlook.

As the situation in natural science now emerges, every scientific field has a corresponding space analog, or even several. Thus physics is paralleled by the whole complex of the astrophysical sciences, chemistry by space chemistry, biology by astrobiology and space biology, etc. Concurrently, each of the terrestrial sciences, irrespective of whether it has or has not its space counterpart, is being pervaded by cosmic material and is also becoming "space-orientated from within", as we said before. This process is still largely controlled by the terrestrial part of natural science, but this state of affairs is not due to last very long.

The rapid expansion of the space sciences and the penetration of cosmic topics into the "earthbound" sciences must ultimately cause qualitative changes in the relationship between the cosmic and the terrestrial branches of science. The space sciences constitute at present extensions of the terrestrial ones, but this situation will eventually be reversed. Thus, for instance, as soon as the structures of some of the planets have been investigated, at least within the solar system, and as our knowledge on the nature of the planets expands, geological science as we know it will probably become a subsidiary discipline. Now, obviously, some "ologies" (e.g., selenology, areology, Venusian geology) form the backbone of astrogeology or planetology, which studies the laws governing the geological development of the planets. When such laws have been established, considerable refinement will be brought into the terrestrial science of geology, as generalizations will be founded not only on the investigation of a single object, i.e., our planet, but on a much broader factual basis. Astrogeology will then no longer be just some exotic application in the existing complex of geologic disciplines, but on the contrary, will include the geology of the Earth as a part, or specialized department (together with other specialities, such as selenology, areology, etc.). The same applies to many other natural sciences.

We are thus witnessing a scientific-technological revolution of great magnitude, in which the pure and applied sciences are divesting themselves of their terrestrial bias and adopting a cosmic outlook. In contrast to the natural science of the prehistorical period, the science of the historical period will be essentially space-orientated—a cosmic science. A major

landmark in the expansion of scientific research into space was the inception of applied astronautics.

We cannot, however, content ourselves merely with reflecting on the fact that science is emerging into space. History never does anything without good reasons. Now such a major event as the orientation of natural science toward space must be due to powerful causes. It is important to contemplate these not only in their basic, theoretical aspect, but also from a practical angle, as this makes it possible to predict to a certain extent the course of development of science and technology and to control the process better. In the present paper this question can be dealt with only briefly and in broad outline.

It is a known fact that science is not something self-contained and an end in itself, but is intimately connected with practice and exists, in the last analysis, for practical purposes. Practice is founded on man's productivity and his relationship with nature, the two being actually inseparably linked. Science meets the demands of practice, and reflects its development and tendencies. Now as analysis shows, human practical affairs, primarily in the domain of industry and in the control of nature, have lately begun to show a distinctly cosmic slant.

The interaction of society with nature (and accordingly, the development of production) always proceeds along four basic lines. There is first of all the process of harnessing natural forces, reflected in the advance of power engineering. In the second place we have the conversion of matter of a given nature, as embodied by the development of mining, metallurgy, chemical engineering, the structural materials industry, and some other techniques. Then we have the processing of living nature (including the eventual artificial synthesis of foodstuffs), exemplified by agriculture and some other branches of production. Lastly, man is also progressing in the control of his own nature, specifically in the form of the extensive practical application of medicine and physiological research to various aspects of human activity. The cosmic trend of the changes now taking place in practice is for the time being most clearly visible in the first two directions, but it is beginning to show first signs in the others as well.

Thus, man is increasingly putting to use forces of a cosmic character. Nuclear and especially thermonuclear power engineering is a good example of the harnessing and utilization by industry of phenomena that are not proper to an ordinary, strictly terrestrial environment, but are quite common in outer space. This is also true for the projects of magnetohydrodynamic electric-power stations, the efforts to produce plasma jet engines, etc.

The industry of transuranic and other artificial chemical elements and isotopes is also in a sense space-orientated, as these substances are not found on Earth and it is only recently that some of them have been detected in the envelopes of stars. Let us stress that what we have in mind is the industrial, and not laboratory, derivation of technetium, plutonium, and scores of radioactive isotopes from raw material available on Earth.

Also of a cosmic nature are many processes of radiation chemistry and physics, of which increasing use is being made in many technologies. Vacuum techniques are being introduced in metallurgy. A great variety of branches are developing in industry and engineering which would be impossible without extremely low temperatures, etc. Accordingly, many production and technological processes as well as new technical equipment and instruments are beginning to rely increasingly upon the artificial reproduction

and practical application of conditions, factors, and phenomena (or their components) which are common in space. Engineering and industry are becoming space-orientated, but it is happening on Earth and not in free space.

All these processes will become intensified when man carries out his activities in space. When manned space stations are put into orbit around the Earth, the Sun, and other celestial bodies, and when large scientific bases are established on other planets, it will be necessary to solve the problems involved in the creation of an artificial environment suitable for human beings. This means altering the natural environment in space. As Marx has said, man is always compelled to struggle with nature in order to maintain his life and propagate, and in the course of this struggle he creates another, artificial, "humanized" nature, which satisfies his needs and demands. Now since man has already had to cope with the problem of creating a more favorable environment for himself on Earth, where he was born and where he evolved, and has even had to employ cosmic forces in the process, he will already be armed when he emerges into space. Furthermore, the conversion of nature in space and the development of a space industry will be spurred by a number of factors that are not commonly found on Earth. First and foremost there are the extreme conditions prevailing in space that are normally fatal to man and which will make it necessary to produce and maintain an artificial environment in space within which man will be able to live and work. There are, in addition, the stringent weight limitations imposed on any material, equipment, stocks of various kinds, etc. that are to be transferred from Earth to another celestial body (whether natural or artificial). These restrictions will make it necessary to make as extensive use as possible of the local (extraterrestrial) resources in raw materials etc., and to develop production on this basis, or as K.E. Tsiolkovskii picturesquely put it, to set up an "ether-borne industry". It is obvious that advances in space engineering and production beyond our planet will exert a reciprocal effect on productive efforts on Earth and speed up their development.

Thus we see that the previously considered space-orientation of natural science represents another, more extensive and profound process — the space-orientation of human practice. These two processes run parallel and are connected in two basic ways (as is the case with the interrelation between scientific knowledge and practical activity). Science meets the requirements of the present moment and helps solve the current problems of production, the control of nature, etc. But it also always anticipates practice, works ahead, and sets about solving such problems as might arise within the distant future. The fact that natural science places its subject matter within a cosmic context enables it to provide an answer to present problems and also to pave the way for forthcoming developments in the space age.

This formulation of the space-orientating factors in science does not, of course, come anywhere near to a full treatment of the subject. Such a treatment is possible only after elucidating the space-orientating factors at work in practice itself. An analysis of this much more difficult question shows that definite regularities operate in the universe, which make it necessary and inevitable that man should emerge into space en masse and later also settle on other planets. Placed in such a light, the space-orientating factors

of science may be studied much more thoroughly. This, however, goes beyond the purview of this article.

REFERENCES

VARVAROV, N. A. and E. T. FADDEEV. Filosofskie problemy astronavtiki (The Philosophical Implications of Space Travel). — In: Voprosy filosofii, No. 8. 1961.

ZABELIN, I. M. Teoriya fizicheskoi geografii (Theory of Physical Geography). — Geografgiz. Moskva. 1959.

PART ONE
MATTER AND PHYSICAL FIELDS

D. D. Ivanenko

THE STRUCTURE OF MATTER AND ATTEMPTS TO CREATE A UNIFIED THEORY OF MATTER

I. EARLY ATTEMPTS TO CREATE A UNIFIED WORLD PICTURE

The possibility of giving a uniform description of matter is a question that was posed in ancient times and has been stirring the minds of scientists and all of mankind ever since. The history of science shows that at times there are unifying, synthesizing tendencies that predominate in physics, when it appears that the world picture has been fundamentally constructed on some particular basis, and that it only remains to fill in the "fine details". During some other phases in the evolution of science analytical tendencies prevail; physicists then investigate new fields and discover new facts, and most scientists are not concerned with any general picture of the world.

For instance, at the end of the 18th century, at which time the fluidic conceptions prevailed, it would have been idle to try to formulate a unified world picture. Similarly, when in the late 19th and early 20th century physicists started probing into the atom and the atomic nucleus, when the old concepts of classical mechanics and electrodynamics were beginning to fail and the new relativistic, quantum, and atomic ideas had not yet been developed, the question of producing a unified picture was relegated to the background. Now, on the other hand, with the quite recent discovery of a large number of elementary particles that are found to be related to each other in a variety of ways, a marked trend may be noted toward developing a unified theory of matter.

If we dwell on the significance of the Leninist assertion on the "inexhaustibility of the electron", and thus of all other particles, we derive the fact that any unified world picture, no matter how successful, will inevitably prove to be temporary and transient. Further developments in the theoretical and experimental investigation of matter, and in space research, are certain to yield facts that do not fit within any given unified picture, thus breaking it up, until new trends toward unification on some higher level arise.

In order to clarify the point under discussion, we will give a brief historical survey of the way in which matter has been interpreted and of the various attempts made to construct a unified picture of the world.

As is known, the science that aimed at reducing every substance to a few, specifically four, elements (water, air, earth, and fire) first appeared in ancient Greece and in the East, in India and China. Plato even assumed that there exists some"protomatter"(the fifth element or quintessence), of which the four elements are the manifestations. Similar ideas have

been expressed in the Indian Vedas, where the fifth element was alternatively represented either as protomatter or as space.

According to Democritus's hypothesis, supported by Epicurus and some other thinkers, all forms of matter are ultimately reducible to very minute particles, or atoms. However, being an opponent of Democritan science, which showed a pronounced materialistic bias, Plato worked out his own particular brand of atomism, in which the atoms of the four elementary substances were identified with the regular solids (a cube, a tetrahedron, etc.)*, and also assumed that it was possible for one element to be transformed into another.

The following important phase in the attempts to construct a unified world picture occurred with the inception of the new physics, at the time of Galilei. The successes achieved in classical mechanics (i.e., nonrelativistic and nonquantum mechanics), whose principal propositions were formulated by Newton, naturally engendered the idea that it must be possible to reduce the laws of motion and of interaction, and all the laws in general, to classical-mechanical laws. This idea was universally held for a long time. Even in the middle and the second half of the 19th century, virtually all the great physicists, among whom were Maxwell, Kirchhoff, Helmholtz, and Kelvin, considered themselves mechanists, at least at the beginning of their scientific career, and elevated the mechanical treatment of real phenomena to the level of an ideal. In point of fact, however, the discovery, back in the middle of the 19th century, of the electromagnetic field as a new form of matter that did not possess a rest mass and did not lend itself in any way to description by the laws of mechanics, requiring, as became subsequently clear, a relativistic treatment, dealt a decisive blow to mechanism. In other words, it was proved that a universal classical-mechanical world picture was not feasible.

This significant fact was not realized until much later, in the period when a radical change occurred in physics, which brought about a crisis, at the end of the 19th and the beginning of the 20th century. The crisis in physics was mainly the result of the attempts of some scientists to interpret the newly discovered quantum, electromagnetic, relativistic, and atomic phenomena in the light of classical mechanics. This crisis has been subjected by V.I. Lenin to a thoroughgoing philosophical analysis, in his well-known book "Materialism and Empiriocriticism".

One of the mechanistic constructions of a world picture, in the 17th and 18th centuries, originated with Descartes, who took as his point of departure the laws of collision and the contact interaction of bodies in conformance with the law he discovered of the conservation of momentum of colliding spheres. In cases when there was no visible contact between the bodies, Cartesian adherents tried providing a speculative explanation, as may be illustrated by the vortex hypothesis they applied to gravitation. Newton and his followers were opposed to such unfounded hypotheses. They took the law of gravitation as a description of facts and did not seek a model in terms of which it could be interpreted (this in fact could not be done even in the 19th century, before the advent of Einstein's theory). Even though many intellects of the 18th century, including Euler and Lomonosov, found the phenomenological approach of the Newtonians hard to accept, still it was no doubt progressive for its time.

* Cf. Plato's "Timaeus".

Thus, in the 17th and 18th centuries, natural processes were interpreted in terms of the laws of classical mechanics. It was assumed that space and time exist independently of matter and of each other, space being taken to be Euclidean and time absolute and unique. Yet, space and time undoubtedly acted somehow on matter, since a free body, for instance, would move along a straight line rather than along any other. As is known, it subsequently became clear that the analysis of the concept of a perfectly "free" body, isolated from any other kind of matter, is a very complex question.

Now the problem of the structure of matter itself was the point of frequent discussions. The atomic hypothesis, set forth in the work of Gassendi and some other scientists, found many adherents. It was, as is known, fairly successfully developed by Bernoulli and Lomonosov, as applied to the treatment of thermal phenomena and the gas laws. However, owing to the impossibility of observing atoms and to the lack of understanding of the chemical laws, these results seemed unwarranted and were eventually completely forgotten. Although Soviet historians of science have shown that the trends set by Lomonosov have been retained in the statements of some Moscow physicists, and in the works of Georgian and other scientists (cf., for instance, V.D. Parkadze's investigations), these were not men of distinction and thus their ideas did not carry sufficient authority to affect the course of development of physics to any appreciable extent.

In the second half of the 18th and the beginning of the 19th century, the investigation of magnetic, electrical, light, and thermal phenomena led to the phenomenological postulation of various "fluids", as special forms of matter. It was assumed that electricity is produced by an electrical fluid, heat by the flow of a caloric, light was interpreted as being vibrations of the ether, etc. Unity was achieved only by the classical-mechanical treatment of any given motion or interaction.

The modern period in the evolution of physics and the creation of a unified world picture fits fairly closely within the span of a century, the 19th, culminating with the discovery of X-rays and radioactivity in 1895-1896, the discovery of the quantum laws in 1900, and the formulation of the theory of relativity in 1905. The 19th century is noted, first of all, for the discovery of a new form of matter, the electromagnetic field, which does not have any rest mass. Secondly, the 19th century saw the unification of different forms of matter; electrical and magnetic phenomena proved to be the manifestation of a single electromagnetic field, and thermal phenomena were basically reduced to mechanical processes, i.e., to the energy of the random motion of atomic particles. The electromagnetic wave also proved to be endowed with thermal properties (like any other kind of matter), viz., energy, temperature, entropy.

An important part in this unification was played by the universal law of conservation of energy, established in the middle of the 19th century (Meyer, Joule, and Helmholtz). When the great significance of energy was realized, attempts were even made to construct a unified world picture on the basis of the concept of energy alone. This picture, propounded by Ostwald, proves to be too restrictive; it blurred the distinctions between the individual properties of the elements, stressed nonatomistic conceptions, and ultimately had an adverse effect on scientific thought. A fundamental discovery was that of one of the elementary carriers of electrical charge, i.e., the negatively charged electron, which was predicted by Helmholtz. This

discovery came relatively late (J.J. Thomson, 1897) and was already associated with the first probings into the atomic world.

Once it had become clear that electrons are a constituent part of every atom and determine its basic optical, magnetic and other properties, and that they carry the current in conductors and produce the chemical bonding of atoms and molecules, the idea naturally occurred of constructing a unified electromagnetic world picture. The components of this picture, it was assumed, would be charged particles and the electromagnetic field.

It must be recognized that the attempt to construct an electromagnetic world picture constituted a logical development and a definite step forward. This picture relied, of course, on the relativistic mechanics of particle motion (rather than Newton's classical laws), since it was with electrons that the laws of motion of fast particles were first verified, while the electromagnetic field itself intrinsically required a relativistic treatment. This is especially true of electromagnetic waves, which move with the limiting velocity of light. It was even suggested to represent charges as singularities within the field itself, or perhaps as some kind of condensations of the field. Let us recall that Lenin clearly perceived the following: that the development of the mechanics of fast particles (essentially, the theory of relativity and the field hypotheses on the structure of the electron) constituted a marked improvement over the former classical-mechanical picture of the world.

The fundamental idea that all the proper energy of the electron resides in the energy of its electromagnetic field was first expressed by Thomson and Abragam. However, the subsequent discovery of the neutron, the neutrino, and of other charged and neutral particles, as well as the interpretation of gravitation in geometrical terms, conclusively showed that it is quite impossible to reduce matter to the electromagnetic field alone. The hypothesis of an electromagnetic world picture therefore quietly gave way, in contrast to the reluctant and tumultuous retreat of mechanism.

Let us dwell in brief on a third serious attempt to construct a unified world picture, which was associated with the founding of Einstein's general theory of relativity (1915).

In a quite unexpected way, Einstein associated gravitation with the curvature of space-time, produced by any kind of matter. According to his theory, the components of the metrical tensor $g_{\mu\nu}$, which describes the curvature of space in Riemannian geometry, are identical with the ten components of the gravitational potential, which is a generalization of the Newtonian potential with its single component.

Einstein's theory of gravitation, which he conceived as a "general theory of relativity" extending to any kind of motion the results of the ordinary "special" theory of relativity, which applies only to rectilinear uniform motion, was a magnificient conception of great profundity, but it introduced in practice only small corrections into the ordinary Newtonian theory.

At the present time, these corrections have been revealed in only three effects:

1) in the small shift of the perihelion of Mercury's orbit, amounting to 43" per century;

2) in the deflection of a light ray in a gravitational field, for instance of the ray coming from a star past the Sun in the space curved by the Sun, amounting to 1.75" (near the edge of the Sun's disk);

3) in the red shift of spectral lines in a gravitational field, which has been detected both for the Sun and for dense stars.

At the beginning of 1960 Pound and Rebka of Harvard University and Cranshaw and his colleagues at Harwell first detected an analog of Einsteinian effects in the laboratory rather than under astronomical conditions. They succeeded in measuring a small line shift in the gamma-ray spectrum emitted by atoms of the isotope Fe^{59} at various heights differing by only a few meters. This was done by making use of a remarkable property of gamma rays, discovered in 1958 by the German physicist Mössbauer. He found that the gamma spectrum emitted by radioactive nuclei of iron atoms located at the lattice points of a crystal exhibits very sharp lines, due to the fact that the recoil momentum is taken up by the lattice.

All these effects prove ultimately that space-time is curved, i.e., that it deviates from a flat, four-dimentional, pseudo-Euclidean continuum. This also vindicates the insights of Lobachevskii, Bolyai, and Riemann, who first established the possibility of a non-Euclidean geometry corresponding not to a flat but to a curved three-dimensional space.

It must be noted that we are referring here to the curvature of the whole four-dimensional world constituted by space and time. The close link between space and time was established, as is known, in the special theory of relativity by its founders, Lorentz, Poincaré, Einstein, and Minkowski (1905-1908).

Besides the three effects derived from the general theory of relativity, Einstein's theory also predicts some other phenomena, the most important of which may be considered the possible existence of gravitational waves, propagated with the speed of light and apparently carrying energy.

Gravitational waves may be in principle revealed either by means of a suitable detector, directed at the Sun or other astronomical objects capable of emitting relatively large pulses of such waves, or else by building some type of powerful gravitational-radiation generator in the laboratory.

In the opinion of J. Weber (U.S.A.), who constructed the first operating setup (1962), the best way of detecting gravitational waves is to use piezoelectric quartz crystals, in which the waves would produce a strain resulting in electrical polarization. V.B. Braginskii and G.I. Rukman (Moscow) recently suggested that the nonstatic character of gravitation may be disclosed by looking for gravitational effects in suitably rotating masses, and came up with a new design for a piezoelectric generator of gravitational waves, based on the use of quadrupole oscillators. It may be noted that some points in the matter are still not very clear, due to the complexity of the nonlinear equations involved. At any rate, the problem of discovering gravitational waves is now placed for the first time on firm experimental ground and is mobilizing the powerful resources of modern radioelectronics and other techniques.

If gravitational waves carrying energy are detected, a new form of matter will have been discovered; this is bound to have many physical implications and might eventually give rise to technological applications. Some experiments have also now been set up for the first time (Fairbank, Nordsieck), designed to display the rotational effects predicted by Einstein's theory (Thirring and Lense, Schiff).

Recently, two interesting experiments were performed which did not yield any basically new findings but provided a more precise means of investigating gravitational phenomena. V.B. Braginskii and G.I. Rukman showed the absence of any screening of gravitation, and thus disproved the

older, less precise, observations of Majorana. Further refinements are none the less expected to exhibit some screening effect. At Princeton (U.S.A.), Dicke demonstrated the equality of inertial and gravitational mass, with a precision fifty times higher than that of the classical Eötvös experiments. Some interesting proposals have been made of trying to detect antigravitation in anti-K-mesons (Podgoretskii, Okonov, and Khrustalev in Dubna).

The success of Einstein's theory, the first to have refined the concept to gravitation since Newton, naturally roused hopes for the possibility of reducing the electromagnetic field, as well as all other fields and properties of matter, to the geometrical properties of space-time.

In 1918 an article by Weyl was published which considered the construction of a geometrized world picture, and it was followed by a large number of works on this same subject.

However, in spite of the enormous number of papers produced on the subject, including many by Einstein himself, and by other eminent theoreticians and mathematicians, which no doubt substantially contributed to the development of higher geometry, the attempts to construct a geometrized unified theory of matter did not achieve any material success.

No new physical results have been obtained (except for one minor achievement, the derivation of the Klein-Gordon equation in five dimensions) which go to establish a relativistic quantum field theory and which are directly applicable (as it later turned out) to π and K-mesons. It should be noted, furthermore, that the aims of such authors were too broad, as they were trying not only to work out a unifield field theory (comprising the gravitational, the electromagnetic, and later also the mesic fields), but also to derive the existence of particles and even of quantum phenomena from geometrical schemes. It has now become clear that this should be attempted on the basis of quantum theory, but in a considerably generalized form. It is therefore not surprising that the flow of papers devoted to a geometrized field theory subsided in the 1920's, when physicists were beginning to develop quantum mechanics, turning in the thirties to the intensive investigation of the atomic nucleus and later of the elementary particles.

Does this mean that the geometrized picture of the world is to be committed to history, like its predecessors, the classical-mechanical and the electromagnetic world pictures?

It appears that this question must be answered in the negative. At the present time, it would no longer occur to anyone to raise the possibility of constructing a purely electromagnetic unified picture of matter, it being manifestly too restrictive and altogether impracticable, whereas a number of leading scientists are still trying to evolve a geometrized unified field theory.

A particularly noteworthy attempt to arrive at a geometrized field theory, proceeding from the wealth of information available on the elementary particles and based on quantum field theory, was made in recent years by the American physicist J.A. Wheeler. His theory, which he regards as a continuation of the works of Riemann, Clifford and Einstein, Wheeler called "geometrodynamics". The field of geometrodynamics constitutes a serious attempt to construct a unified world picture. Work on it has still not gone beyond Princeton University, but it has already drawn the attention of scientific circles, for instance, at recent international conferences

on gravitation (at Royaumont in 1959 and, to a lesser extent, at Jablonna-Warsaw in 1962), and in the scientific literature of the last few years.

Geometrodynamics, like any other theory of matter, can be realistic only if it takes into account quantum phenomena. Quantum geometrodynamics, following behind the classical theory, is just making its first steps. It stresses the topological aspects of geometry and emphasizes the fundamental role which is bound to be played by quantum fluctuations (random deviations) of the metric.

Fluctuations of the vacuum necessarily take place in any kind of field. It is, for instance, well known that when the vacuum fluctuations of the photon field and electron-positron field "knock off" an electron, they shift slightly the energy levels of the electron, as Lamb has shown for the electron in the hydrogen atom (1947). The theory of the Lamb shift has been developed to a high degree of precision and has been found in excellent agreement with experiments. In the course of developing the theory some methods typical of modern quantum field theory were worked out; for instance, various singular functions were used, entirely relativistic calculations were made, and the infinite electromagnetic mass, and in general any field mass, of particles (and also the field portions of the charge and other coupling constants) were isolated by means of the "renormalization" procedure.

The necessity of taking into account the fluctuations of a weak gravitational field was pointed out in some of our papers, and also recently by D.I. Blokhintsev. Wheeler goes even farther than that and makes the daring assumption that there may be fluctuations of all the gravitational potentials and of the metrical tensor, and points out that at very small distances of the order of the critical universal gravitational length $r \sim \sqrt{\frac{\hbar G}{c^3}} \approx 10^{-32}$ cm, where G is the gravitational constant, such fluctuations must attain considerable values. This may cause the topology of space to change, with the formation of multiply connected regions, gaps, holes connected by "shafts", etc. The suggestion as to the necessity of fluctuations in the metric or in the gravitational field and the need for taking into account topological factors, which have been disregarded before, seem to be the most significant aspects of geometrodynamics. The theory also puts forward the hypothesis that the "bare" electron, without its surrounding field, which is associated, according to quantum theory, with nonrenormalized mass and charge, may be identified with a hole; its antiparticle, the positron, is then identified with the hole at the other end of the "shaft". However, quite independently of the incompleteness of classical geometrodynamics, there is in quantum geometrodynamics a fundamental difficulty, stemming from the fact that, proceeding from a metric described by a second-rank tensor (in other words, from a Bose gravitational field, whose waves have a spin $S=2$, in fractions of $\frac{\hbar}{2\pi}$), it is very difficult to go over to fermions, in particular to electrons and neutrinos, represented by spinors (which may be described as semivectors or tensors of rank $1/2$), and possessing half-integral spin, $S=1/2$. Let us remark at this point that, on the other hand, modern unified nonlinear spinor theory considers fermions as basic, although it is not yet capable of describing the total gravitational field. In any case, Wheeler's interesting and stimulating work on geometrodynamics has its positive side, in that it

endeavors to link the theory of elementary particles with the processes occurring in stars, galaxies, and all the known universe. Wheeler also considered "geons" —hypothetical giant concentrations of the electromagnetic field, or of neutrinos, or of the gravitational field, held together by their own gravity. We may note in this connection that Wheeler entertains the hypothesis, as we do, that it may be possible for electron-positron and other particle pairs to be transformed not only into photons but also into gravitons (and also for proton-antiproton pairs to change into π mesons); moreover, he believes, conversely, that it may be possible for the gravitational field to be transformed into ordinary matter. Somewhat earlier we calculated, together with A. A. Sokolov and A. M. Brodskii, the probability of an electron-positron pair (or more precisely, of two scalar particles) transforming into two gravitons, as defined by the effective cross section:

$$\sigma = 24\pi r_g^2 \frac{c}{v}\left(\frac{E}{mc^2}\right)^2,$$

where $r_g = \frac{Gm}{c^2}$ is the gravitational radius of the particle, E is the energy, v is the velocity of the electron, and c is the velocity of light. Afterward, I. Piir (at Tartu) computed the probability of transformation of photons into gravitons, and Wheeler and Brill estimated the probability of transformation of a neutrino-antineutrino pair into gravitons. More precise calculations were recently carried out by Vladimirov and Feynman. Considerable attention is devoted in these papers to various cases of emission of gravitational waves (in the motion of stars, or of whole galaxies) and their subsequent behavior is analyzed, specifically with respect to the expansion of the universe.

When determining the stability conditions of the motions of astronomical objects, account has to be taken of the gravitational waves emitted over billions of years. If the gravitational waves reach some state of equilibrium, a definite temperature must be assigned to them, in the same way as for a neutrino gas.

We may mention at this point that quite recently efforts have been directed toward developing another generalization of Einsteinian theory, involving "twisted" rather than curved space-time. The geometry of a space twisted on itself was proposed as early as the twenties by Cartan, Einstein, and Weizenbeck, but it failed to yield any concrete physical results. Not long ago, however, V. Rodichev and R. Finkel'shtein showed that in twisted space a nonlinear correction automatically crops up in the Dirac equation used to describe electrons, protons, and all other fermions, the correction being exactly of the pseudovector type required by a unified nonlinear spinor theory of matter. The point has also been made by Møller that it may be worthwhile adopting a special instance of twisted space (one in which there is absolute parallelism) in order to derive an effective expression for the energy of the gravitational field; in terms of Riemannian-Einsteinian curved space this has not yet been satisfactorily realized.

It seems likely that the new treatment of the gravitational field, similarly to the electromagnetic and other Bose fields, as some kind of "compensating" field (in accordance with the ideas of Yang and Mills and of Sakurai, which have been supported by Gell-Mann, Schwinger, and Feynman and applied to

the case of gravitation in the studies of Utiyama, Kibble, and Brodskii-Ivanenko-Sokolik) should normally lead to the existence of a twist in space. It is still too early to say that space-time has been definitely proved to be twisted, but a significant attempt has certainly been made to generalize Einstein's theory in this direction.

Mention should also be made of the various cosmological investigations which seek to generalize A. A. Fridman's theory, proceeding from the Einsteinian equations for a nonstationary expanding universe. The investigations cover the case of a rotating anisotropic universe (Zel'manov, Gödel, and Schüking) and the theory of a universe in expansion but having constant density (Bondi, Hoyle); this already goes beyond the Einstein-Fridman models proper.

There is a particular generalization of Einsteinian theory that stands apart, involved with the Dirac hypothesis on the slow secular decrease in the gravitational constant. Jordan, Dicke, and some other scientists have shown that this hypothesis has many astronomical and geological consequences, such as the fact the Earth is slowly expanding. Significantly enough, there are some geologists who also claim that the Earth is expanding at the rate of about half a millimeter per year (Egyed, Wilson, cf. also V. B. Neiman). It would be interesting to correlate this expansion with the secular increase in the length of the day (Ivanenko-Sagitov), and perhaps also with the formation of the network of gigantic cracks on the Earth (Peive, Heezen, and others). At any rate, studies in gravitation, space-time and cosmology are proceeding at a lively pace, and they are bound to yield findings of fundamental significance for an integral world picture.

II. MODERN IDEAS ON THE STRUCTURE OF MATTER. ATOMS, NUCLEI, AND ELEMENTARY PARTICLES

Let us now pause to examine the structure of "ordinary" matter, atoms, nuclei, and elementary particles, leaving out gravitation for the moment. In the interaction of particles of any accessible energy, up to energies of about 10^{17} or 10^{18} ev detected in cosmic rays, at all the small distances attained, down to distances of about $l=10^{-14}$ cm, the gravitational forces are vanishingly small with respect to the electromagnetic forces, and even more so as compared with nuclear forces. The question as to the effect gravitational forces have on the inner structure, i.e., the core of particles, is still a moot point; there, it seems, they have to be taken into account.

Before tackling the classification of particles and the construction of what may be termed a unified "atomic" picture of matter, let us recall briefly the current concepts of the structure of atoms and nuclei, and the main events in the discovery of elementary particles.

The contemporary attempts at producing a quantum atomic picture of matter constitute a fourth stage, following the attempts at a universal mechanical, electromagnetic, and geometrical world picture.

As is known, all substances occurring in nature are basically made up of atoms of various chemical elements. The systematization of the elements was achieved by D. I. Mendeleev, who arranged them in a table by increasing order of atomic weight. The serial number of an element in Mendeleev's

periodic table is equal to the charge of the atomic nucleus or to the number of electrons in the neutral atom. The structure of the atoms of all the elements is in a sense similar to the solar system: at the center is located the positively charged nucleus, around which revolve the negatively charged electrons. The parallel with the solar system, which was demonstrated by Rutherford in 1911, is not accidental: it derives from the fact that Newton's law of attraction in the solar system on the one hand, and the Coulomb law of electrical attraction between the electrons and the nucleus in atoms on the other, are expressed by the same dependence on the distance. In both cases the force of attraction varies in inverse ratio to the square of the distance:

$$F_N = \frac{GmM}{r^2}; \quad F_C = \frac{e_1 e_2}{r^2}.$$

The magnitude of the force of electrical attraction between the electrons and the nucleus is, however, immensely larger than that of the force of gravitation between them, by a factor of about 10^{40}!

And this is where the similarity ends. The most important difference between an atom and the solar system resides in the fact that the electrons and atomic nuclei do not obey the laws of classical mechanics but those of quantum mechanics. It is possible to speak of the orbits of electrons only as a rough approximation, in the sense of their being the most probable trajectories, as the motion of the electron cannot really be visualized in classical terms; the electron may be seen to move everywhere within the atom.

What is involved in essence is that the state of an atom is defined by a probability wave, viz., the ψ wave. The atom settles into one of a set of stationary states, in each of which the electrons may be described as revolving about the nucleus along definite orbits (i.e., the most probable ones) containing an integral number of waves.

The energies of the atomic electrons can assume only a discrete (discontinuous) series of values. When an electron "jumps" from one state to another in the atom, it either emits or absorbs a definite amount of electromagnetic energy (a quantum of light or a photon):

$$E = h\nu.$$

The fact that the electron exhibits wave properties, and all the other remarkable predictions of the quantum (wave) mechanics founded by Bohr, Sommerfeld, de Broglie, Heisenberg, Schrödinger, Dirac, and Born, have been brilliantly verified by many experiments. We will not delve into the interpretation of quantum mechanics, however, since we are interested at this point only in the structure of matter.

In the simple and light hydrogen atom, there is one electron revolving around a proton. In the helium atom, there are two electrons revolving around a nucleus having a charge of +2. The atomic nuclei are, in turn, complex systems, consisting of protons and neutrons, as it was eventually found after the discovery of the neutron and after theoretical analysis. In the atom of uranium, which is element No. 92 in the periodic table, 92 electrons revolve around a nucleus of charge +92, consisting of 92 protons and 146

neutrons (the principal uranium isotope U_{92}^{238}). For a long time after Mendeleev the list of known elements did not go beyond uranium. In the 1930's and 1940's, the elements missing from the periodic table, Nos. 61, 73, and 75, were obtained by nuclear bombardment. In the same way, the use of nuclear reactions finally provided the means of going beyond the limits of the old system of elements and of obtaining one after another an ever-increasing group of transuranic elements, beginning with neptunium—Np (No. 93), and plutonium—Pu (No. 94), which is of importance in nuclear engineering, through the subsequently discovered elements americium—Am (No. 95), curium—Cm (No. 96), berkelium—Bk (No. 97), californium—Cf (No. 98), einsteinium—Es (No. 99), fermium—Fm (No. 100), and up to mendelevium—Md (No. 101). At the present time Swedish, Soviet, and American physicists are trying to determine the property of element No. 102, No (nobelium), whose name has not yet been definitely decided upon. Quite recently element No. 103, Lw (lawrencium), was discovered. As we see, the new transuranic elements are named not only after geographical places but also after great scientists whose work has been associated with the discovery of new elements, with studies on the atomic nucleus, and with the construction of particle accelerators, such as Curie, Einstein, Fermi, Mendeleev, and Lawrence.

Without going now into the details of atomic structure, the arrangement of electrons into shells, or the interesting properties of the transuranic elements, let us just point out that the question naturally arising as to the top limit of the periodic system of elements, i.e., the largest possible number of nuclei which are stable to any appreciable extent, has not yet been finally settled. It is well known that, without exception, all the nuclei of isotopes from No. 84 on are radioactive, i.e., they disintegrate spontaneously with the emission of either helium nuclei (designated as α particles) or β particles (electrons) and of γ rays. Many nuclei of the heavier elements spontaneously decay into two or more fragments of approximately equal size. This effect was discovered by G. N. Flerov and K. A. Petrzhak shortly after Hahn had demonstrated the fission of uranium by neutron bombardment.

Recently a detailed study was made of the spontaneous fission of element No. 102 into 3 fragments. The rough theoretical estimates worked out by Wheeler yielded at first the rather exaggerated value of $Z_c \approx 200$, and later $Z_c \approx 140$ for the possible number of the significantly stable elements. The calculations we performed together with N. N. Kolesnikov gave the more "pessimistic" estimate of about $Z_c \approx 110$-120 for the number of possible elements.

The latest data seem to support the more conservative estimates. This means that the nuclei of the elements with $Z_c \approx 110-120$ ought to disintegrate within a very short time, mainly by spontaneous fission, and thus the existence of atoms with such nuclei (or with any heavier ones) must be impossible. Alpha decay by spontaneous fission is caused by the fact that when there is a large number of protons in the nucleus, i.e., in elements with a high Z_c number, where $\frac{Z_c^2}{A} \approx 40$, the electrical forces of repulsion become so considerable that they are no longer balanced by the nuclear forces of attraction between the protons and neutrons. A recent discovery was that of proton radioactivity (G. N. Flerov, V. I. Gol'danskii).

Let us now turn to the atomic nucleus. After the discovery of the neutron by Chadwick, and our preliminary investigations started in collaboration with V.A. Ambartsumyan, we established the fact that the atomic nucleus can consist only of heavy particles, viz., protons and neutrons (nucleons), and does not contain either electrons or any other leptons (light particles), i. e., positrons or μ mesons.

It was later found that some newly discovered super-heavy particles, such as the lambda hyperon (Λ), may also be included in nuclei, though not of the ordinary kind, but in hypernuclei that are occasionally formed in certain types of reactions.

The hyperons, as we shall subsequently see, may be considered in many respects as excited states of nucleons, and thus the currently accepted model of the nucleus, a somewhat generalized form of the older version, has it that all nuclei consist of heavy particles, or baryons (nucleons and hyperons), held together by short-range forces, essentially of the π-meson type.

The type of forces involved must be specified, since there is evidence that a very short-lived, metastable system can be formed by nucleons, such as the proton and antiproton, which is held together by electrical rather than nuclear forces. An example is the positronium atom, formed by an electron and a positron.

Our proton-neutron model, supported primarily by W. Heisenberg and E. N. Gapon, quickly came to be ranked with the other existing models of Auger, Perrin, and Dirac, which postulated nuclei containing protons, neutrons, and electrons. It left, however, one basic question to be answered: what is the explanation for the emission of electrons, and of what was later recognized as antineutrinos, in the natural beta-decay of nuclei, or in artificially induced beta-decay later discovered by Fermi? Also, what is the explanation for the corresponding emission of positrons and neutrinos in positron decay, discovered by the Joliot-Curie team in 1934?

The answer, as it turned out, gave rise to animated controversy. It states that the protons and neutrons composing the nucleus are elementary particles, not consisting of any other actual particles. Beta-decay is a generative action, involving the emission of new particles (electrons, neutrinos), in the same way as in the emission of protons by atomic electrons or of gamma protons by nuclear particles, new particles are produced which were not initially present in the radiating system. This interpretation of beta-decay was also adopted by Blackett and Occhialini, who discovered together with Anderson the positron and the production and annihilation of electron-positron pairs. In this respect their work may be considered as definite proof of the proton-neutron model of the nucleus which may be said to have been universally accepted at the First Soviet Nuclear Conference and at the International Conference on Nuclear Science held at Solvay in 1933.

All the isotopes of the 103 known elements of the periodic system are made up of only three kinds of elementary particles—protons, neutrons, and electrons.

Let us illustrate the point by means of two familiar examples, which may be helpful in our subsequent discussion. The neutral hydrogen atom consists of a single electron revolving around a proton (light hydrogen), and that of deuterium consists of an electron revolving around a deuteron ($D=H_1^2$), i. e., the hydrogen isotope known as heavy hydrogen, which consists of a proton

and a neutron. Lastly, in the radioactive isotope of hydrogen, tritium ($T=H_1^3$), the electron revolves around a triton nucleus, made up of a proton and two neutrons.

If hypernuclei are taken into consideration, further types of hydrogen are possible: the hypertriton $\Lambda—H_1^3$, in which one of the neutrons is replaced by a lambda hyperon, or even a hypernucleus of hydrogen of atomic weight 4, $\Lambda—H_4^1$, in which the electron revolves around a nucleus made up of one proton, two neutrons, and one Λ_0 hyperon.

In regard to the various possible types of hydrogen it is also relevant to point out that not only electrons but also negative muons, pions, or K mesons may also revolve around ordinary nuclei (or around hypernuclei), thus forming mesic hydrogen, or, correspondingly, other π-, μ-, and K-mesic atoms. The μ-and π-mesic atoms were discovered at the beginning of the fifties by Rainwater and Fitch; these atoms are characterized by distinctive spectra and they have been fairly well investigated by now throughout the range of elements from mesic hydrogen to mesic lead.

A significant aspect of mesic atoms is the fact that the motion of the meson is appreciably affected by the distribution of protonic charge over the nucleus. This is because the mesons have larger mass, and their orbits are much closer to the nucleus than electron orbits. The mesons in heavy mesic atoms move very close to the surface and sometimes even jump through the nucleus. Clearly, the study of mesic atoms can yield valuable information on the structure, size and shape of nuclei, and some important data have already been obtained in this way. In particular, the use of mesic atoms has provided the most accurate measurement of the size of nuclei.

Now since the atoms of all the chemical elements occurring in nature turn out to be built of three kinds of elementary particles, the electrons, protons, and neutrons, it might be assumed that other forms of matter, that is to say, other particles, play no part in the atoms or nuclei and are produced only by various nuclear reactions in cosmic rays or in the laboratory. In point of fact, such is not the case. Aside from the three types of particles actually present in atoms, the latter also contain (in a latent or virtual state, so to speak) fields responsible for the coupling forces between the particles. The electron, for instance, is attracted to the nucleus mainly because of electrostatic forces (other electromagnetic forces play an insignificant part). The atoms emit this field in bundles taking the form of photons, when the electrons pass from a higher to a lower energy level or when atoms collide with each other. The photon, which is the field quantum of energy $E=h\nu$, is quite similar to any other particle: it possesses a definite angular momentum (spin), $S = 1 \cdot \frac{h}{2\pi}$; an aggregate of photons, like other particles with integral spin, obeys the Bose statistics. Such "bosons" are also the π and K mesons, which have no spin, and the as yet hypothetical gravitons of spin 2. The basic difference between the photon and other particles such as the electron is that the photon has no rest mass. Furthermore, the electrons, protons, μ mesons, neutrons, neutrinos, and all the hyperons, possess half-integral spin (in units of $h/2\pi$) and obey the Fermi-Dirac statistics. All such "fermions" are subject to Pauli's exclusion principle, which states that any energy state of given momentum can contain only two fermions with antiparallel spin momenta.

The electromagnetic field is also present in a virtual, unradiated state in nuclei, and causes the electrostatic repulsion between protons and the

magnetic interaction between protons and neutrons (since both these nucleons possess magnetic moments). These facts have actually been known for quite a while, and until recently only some very fine quantum corrections, often difficult to calculate or to measure, have been found. In particular, one of the major events in postwar physics was Lamb's discovery in 1947 of the small additional shift in the energy levels of the electron in the hydrogen atom. The Lamb shift, which is a correction of the one obtained by Dirac's relativistic theory generalizing the results of Bohr, Sommerfeld, and Schrödinger, proved to be the result of the interaction of the electron with the fluctuations (deviations) in the "zero-point" oscillations of the photonic field and the electron-positron field, which had not been taken into account before (the calculation of Bethe, Schwinger, Feynman, and Dyson). During the same period, in 1947, Kusch, working with radio electronics at the Rabi Laboratory of Colombia University, discovered a small correction to the magnetic moment of the electron, i.e., to the usual Bohr magneton. He found that the magnetic moment of the electron is:

$$\mu_e \approx \mu_0 \cdot 1.001165;$$
$$\mu_0 = \frac{eh}{4\pi mc}.$$

This "anomalous" correction turned out to be due to the so-called "vacuum" effects, which may be visualized as the electron being shaken from its position under the impact of the photons continually produced by random fluctuation, even though the average electromagnetic field may be zero, and also partly by the fluctuation of the electron-positron pairs whose field surrounds the electron.

We now turn to another very important fact. In addition to the electromagnetic field, there are in atomic nuclei also other fields, responsible for nuclear forces. The fundamental forces that hold the proton and neutron together in the nucleus are neither gravitational nor electromagnetic. The field of nuclear forces, which are tremendously strong, thus displays distinctive characteristics, such as the fact that its particles possess rest mass. This was established in the early theoretical studies made of nuclear forces, which were supposed to be due to electron-antineutrino (or positron-neutrino) pairs (Tamm, Ivanenko, and later Heisenberg, Sokolov). A subsequent signal achievement was that of the Japanese physicist Yukawa, who predicted the existence of a new, mesic field that is responsible for the nuclear forces and whose quanta in the free state are the particles called mesons, having an intermediate mass between that of the electron and the nucleon (1935). It proved very difficult to cause the emission of mesons, i.e., to separate the nuclear field from the nucleons, for the reason that the mesons represent a "strong" coupling, in fact the strongest known as yet between any kind of particles. Quanta of the nuclear field, emitted by atomic nuclei in the collisions between protons or neutrons, were discovered in 1947 by Powell and indeed turned out to be particles with a mass of 274 m (electron masses). As theoretically predicted, they possess integral spin, or, more precisely, zero spin. These particles were named π mesons, or "pions" (the Greek letter π was used to stand for the words "primary" and "Powell").

It is thus fundamentally the pionic field that gives rise to the nuclear forces, in the same way as the electric field between protons and electrons is caused by their charges. The nuclear forces between nucleons are produced by one nucleon emitting a pion and another absorbing it. There are also neutral pions which are slightly lighter, with a mass of 264 m. Great advances have been made in the theory of interaction of nucleons and pions and in the experimental work associated with it, and it is now possible to explain many things about the scattering of pions, their production, and absorption. The theory of nuclear forces, which must be essentially due to π mesons, also elucidated many important points on the interaction between nucleons, in particular the fact that the forces are short-range, charge-independent, and central, and also on the form of spin dependence.

The calculation of the nuclear forces at extremely small ranges is actually quite difficult, owing to the fact that many factors have to be taken into account: the recoil of the nucleon in meson exchange, the exchange of two or more pions, vacuum corrections, relativistic corrections for time differences between individual nucleons, K meson exchange, and, lastly, it is also very important to take into consideration the inner structure of the nucleons themselves.

According to modern views the nucleon (a proton or a neutron) consists of some kind of "kernel", surrounded by a cloud or "fuzz" of pions and K mesons. At very short ranges, therefore, the forces between the pions themselves should come into play, which has only very recently began to be taken into account. Finally, it is possible, as was recently proposed by Sakurai, that the primary field directly associated with the nucleons is some still hypothetical vector field of "intermediate mesons", and that the π mesons are only the decay product of the latter. All this shows that the theory of nuclear forces has not yet reached any final form.

As we now understand it then, the atom with its nucleus is constituted of electrons, protons, and neutrons (in actual form), together with the electromagnetic and mesic fields (in latent form). Thus it might seem that the investigation of the structure of matter has now been completed. As it turns outs, however, the structure of matter cannot be explained by these particles alone, because a whole new set of elementary particles, closely associated with the former, has been lately discovered.

First of all, it was found that the neutrons and pions are unstable particles, i.e., they spontaneously decay, giving birth to new particles that are not directly involved in the structure of matter. The charged π mesons invariably decay after an average lifetime of about $2 \cdot 10^{-6}$ sec, producing two new particles: a neutrino or an antineutrino, together with a new meson-type particle, known as the μ meson or "muon" (discovered in cosmic rays in 1937):

$$\pi^+ \to \mu^+ + \nu; \quad \pi^- \to \mu^- + \bar{\nu}.$$

Neutral muons have never been found. The neutral pion decays within an extremely short time, after about 10^{-16} sec, giving rise to two gamma photons: $\pi^0 \to 2\gamma$.

Approximately one ten-thousandth of the pions decay according to the scheme:

$$\pi^- \to e^- + \bar{\nu}.$$

The free neutron invariably decays after a lifetime of about 12 minutes into a proton, an electron, and an antineutrino:

$$n \to p + e^- + \bar{\nu}.$$

The decay of a neutron within the nucleus depends on the stability of the whole nucleus; the electrons produced in this case are termed beta particles. The reverse process, the absorption of an electron by a nuclear proton, is known as K capture: $e_- + p \to n + \nu$. The free protons are stable, while an excited nuclear proton decays according to the scheme:

$$p \to n + e_+ + \nu,$$

giving birth to a new particle, the positron, which is essentially similar to the electron; the positron has the same mass and spin, only its charge and magnetic moment are positive. Further, the positron has the lepton number $l=-1$ (in the electron $l=+1$) and a preferred positive "helicity", in opposition to the electron. The positron is thus said to be the antiparticle of the electron. Electron-positron pairs may be produced when gamma photons hit atomic nuclei. The μ^+ and μ^- mesons are also "mirror" antiparticles and have lepton charges of opposite sign.

The helicity is measured by the relative direction of the spin and the momentum. The beta-decay electrons, which have a preferred negative helicity, thus have a spin with a sense opposite to the motion. The remarkable new property of "helicity", which is most clearly exhibited in neutrinos (which have no rest mass), was discovered in 1956-1957 by the Chinese physicists Lee, Yang, and Wu. The characteristic polarization phenomena resulting from helicity have been studied in detail by Soviet, American, and other physicists (Alikhanov, Sokolov, Kerimov, Touschek, Tolhoek, and others).

Of course, the process of the production of an electron-positron pair may be reversed; the electron and positron are then annihilated and $e_- - e_+$ are transformed into photons:

$e_- + e_+ \to 2\gamma$ (for particles with antiparallel spin),

$e_- + e_+ \to 3\gamma$ (for particles with parallel spin).

These remarkable processes of the production and annihilation of particles possessing rest mass from and into field quanta that have no rest mass were predicted by Dirac and then observed in practice, in full agreement with the theoretical result, first in cosmic rays (Blackett and Occhialini, 1933) and later by inducing them in the laboratory. It was subsequently found that all the particles may be produced under suitably given conditions, and on the other hand, that all the particles may transform into others, either spontaneously (like the neutron and π meson) or by colliding with another particle of the appropriate kind. Consequently, there is no such thing as a perfectly stable particle.

In addition, it is possible for an electron and a positron to form a metastable system, positronium, in which the electron and the positron move around their common center of gravity. The positronium atom must eventually transform, either into two photons after about 10^{-10} sec (in the case of parapositronium), or into three photons after about 10^{-7} sec (in the case of orthopositronium).

During the time it exists, the positronium may combine into molecules with other atoms or diffuse through matter to a considerable distance.

Let us now return to the products of π-meson decay, the μ mesons; the latter decay spontaneously, and their decay reactions are:

$$\mu^- \to e_- + \nu + \bar{\nu}',$$
$$\mu^+ \to e_+ + \nu + \bar{\nu}'.$$

Thus, it would have also been possible to come to the discovery of positrons by studying the decay of positive muons. Until recently it was quite clear that the decay of muons gives rise to neutrinos and antineutrinos. However, assumptions have been entertained for some time now that there actually exist two types of neutrinos and antineutrinos; the neutrino ν and the antineutrino $\bar{\nu}$ are associated with positron or electron beta-decay or K capture, i.e., with processes of the type $e_- + p \to n + \nu$, while the other type of neutrino, ν', and antineutrino, $\bar{\nu}'$ (sometimes called neutrettos for the sake of distinction) are associated with muon decay. In the summer of 1962 the American physicists Lederman and Steinberger conclusively proved the existence of neutrinos of the other, μ-meson type. Their experiment was based on the fact that the absorption of the ordinary, beta-decay anti-neutrinos by protons leads to the production of positrons (as was shown by Reines and Cowan):

$$\nu + p \to n + e_+,$$

whereas the neutrinos produced together with μ mesons, on being absorbed give rise to μ mesons again, and not to electrons or positrons!

The reactions are thus as follows:

$$\pi^+ \to \mu^+ + \nu',$$
$$\pi^+ \to e^+ + \nu.$$

An important advance was made in the fall of 1955 at Berkeley by Segré and Chamberlain, who, after searching for a long time in cosmic rays and in the laboratory, proved the existence of the antiproton and later of the antineutron. The antiproton is the antiparticle of the proton; it has the same mass and the same charge, except that its charge is opposite (negative). It has a negative magnetic moment and is designated by the baryon (heavy) number $B = -1$, while for the proton $B = +1$. Like the electrons and positrons, when protons and antiprotons collide they may transform into gamma photons, though their transformation into π mesons has a much higher probability. In that case, at moderate energies, about 5 pions are produced on the average:

$$p + \bar{p} \to \approx 5\pi.$$

These most interesting particles—the beta-decay and the μ-meson neutrinos ($\nu_1 + \nu_2$) and their corresponding antiparticles, the antineutrinos ($\bar{\nu}_1 + \bar{\nu}_2$) —have no rest mass, like the photons, but, unlike the photons which have integral spin ($S = 1\ \frac{h}{2}\pi$) they possess half-integral spin ($S = \frac{1}{2}\ \frac{h}{2}\pi$), like the electrons. It has been shown with great precision that beta-decay

neutrinos lack any rest mass; the mass of the μ-meson neutrinos is either exactly zero, or at the most extremely small. Being devoid of charge or magnetic moment, the neutrinos interact very weakly with other particles and have a high penetrating power. The neutrino differs from the antineutrino, its antiparticle, by its helicity, which may be represented as the direction of the spin with reference to the direction of motion, as well as by the sign of its lepton charge. Like the photons, the massless neutrinos move at the speed of light. The existence of the neutrino was predicted at the beginning of the thirties by Pauli on the basis of an analysis of the energy balance in beta-decay, and was later indirectly confirmed by the success achieved by the theory of beta-decay formulated by F. Perrin and particularly developed by E. Fermi in 1934. Direct experimental evidence was secured much later, in the middle of the fifties, when Cowan and Reines with their colleagues detected a stream of antineutrinos shooting out of a nuclear reactor. The neutrinos were produced in the beta-decay of excited nuclear fragments resulting from the fission of uranium. It proved possible to observe the reaction of antineutrino capture by protons in a bubble chamber, with the transformation of these particles into a neutron and positron:

$$p + \bar{\nu} \rightarrow n + e_{+}.$$

It is interesting to note that an appreciable part, about 10%, of the energy of the Sun and other stars is carried off into space in the form of neutrinos, which are emitted in the thermonuclear reactions occurring in stellar interiors.

When the particles with which we are already familiar (pions, protons, neutrons, etc.) go into high-energy collisions a whole flock of particles are produced, and together with the π mesons and nucleons there appear new particles, specifically "superheavy" particles, the hyperons, whose mass exceeds that of the nucleons (the protons and neutrons) and new types of K mesons ("kaons"), which are heavier than the pions. It is significant that such processes once again produce a variety of "antiparticles", or charge-conjugate particles, which are "mirror images" of the ordinary particles.

Let us write down a couple of typical reactions of the production of new particles:

$$\pi^{-} + p \rightarrow \Lambda_0 + K^0$$
$$\rightarrow K^{+} + \Sigma^{-},$$

where Λ_0 is a lambda hyperon and Σ^{-} is a sigma hyperon.

The K mesons (the kaons) also turned out to be quite interesting particles, though strictly speaking there is no such thing as a dull particle, which does not display any distinctive characteristics. Furthermore, it appears that the only way to understand the properties of each particle is to consider them in their ensemble, similarly to a symphony orchestra, in which it is impossible to eliminate any individual instrument without impairing the total effect. The K mesons decay in diverse ways—into two or three π mesons, and alternatively into two or three particles together with leptons. Given

below are some typical instances of K-meson decay:

$$K^+ \to \pi^+ + \pi^0$$
$$\pi^+ + \pi^+ + \pi^0$$
$$\pi^+ + \pi^0 + \pi^0$$
$$e^+ + \nu + \pi^0$$
$$e^+ + \nu$$
$$\mu^+ + \nu + \pi^0$$
$$\mu^+ + \nu.$$

A single kaon track was discovered in 1941 by Leprince-Ringuet. After that investigators began to find many new particles in the range of 900-1200 m, and it was thought for a long time that there was a τ particle which decays into three pions, and a θ particle which transforms into two pions. It finally turned out that these are charged and neutral K mesons of virtually identical mass (966 m). To be precise, the neutral kaon is slightly heavier, with a mass of 974 m.

As we climb up the scale of particle masses, we encounter for the first time the "strange" particles, in the guise of the K mesons. To the class of the strange particles belong all the hyperons. The first unusual property of the strange particles is the fact that they are produced in pairs. For instance, when high-energy π mesons collide with protons, among the particles produced there are always either two K mesons, or two hyperons, or a hyperon and a K meson. This is suggestive of the fact that the strange particles might possess some new property which is conserved, in a way similar to the electric or lepton charge. Thus, for instance, electrons are produced in pairs with positrons or neutrinos. The new conserved property of the K mesons and the hyperons was half-jokingly called strangeness. If the K^+meson is assigned the strangeness $S = +1$, then its antiparticle, the K^- meson, will have the strangeness $S = -1$, K^0 will have $S = +1$, and $\bar{K}^0$ will have $S = -1$.

We will not dwell in detail on all the phases of development in the discovery of the hyperons, but only mention that the first superheavy particle, the neutral Λ hyperon, was discovered in the analysis of cosmic-ray tracks by Butler and Rochester in 1947, which was a very eventful year for physics. The mass of the Λ hyperon is equal to 2183 m, and its strangeness $S=-1$. Shortly afterward the heavier Σ hyperons, both charged and neutral, were discovered, and, finally, the heaviest of all the known particles—the cascade Ξ hyperons. All the baryons, i.e., the nucleons and the hyperons, have a spin $S=1/2$, which means that they are fermions. The concept of strangeness was first introduced by Gell-Mann and Nishijima and stands as a landmark in the physics of elementary particles, as it may be possible to analyze and interpret the complicated reactions in the production and decay of the strange particles, i.e., the hyperons and kaons, and of some nonstrange particles as well—the pions and nucleons.

The π particles, K particles, and the baryons form together a group known as the strongly interacting particles. They are distinguished from the leptons, or the light particles, i.e., the electron, the two types of

neutrino, the muon, and the corresponding antiparticles, which are characterized by interactions of much lower intensity, the so-called weak interactions. In addition, of course, all the charged particles, whether light (the leptons), medium (the mesons), or heavy (the baryons), interact with each other by means of the electromagnetic field.

When strange particles are produced by strong interaction the strangeness is conserved (two particles of opposite strangeness are produced), but in the decay of strange particles, which is due to weak interactions, the strangeness is not conserved. For instance,

$$\Lambda_0 \to p + \pi^-; \quad \Sigma^+ \to n + \pi^+; \quad \Sigma^0 \to \Lambda^0 + \gamma; \quad \Xi^- \to \begin{cases} \Lambda + \pi^- \\ \Sigma^- + \pi^0 \\ \Sigma^0 + \pi^- \end{cases}$$

$$\Lambda_0 \to n + \pi^0; \quad \Sigma^+ \to p + \pi^0.$$

The hyperons thus live relatively long, compared to nuclear lifetimes of $T \sim \frac{R}{C} \sim \frac{10^{-13}}{10^{10}} \approx \sim 10^{-23}$; their lifetime is about 10^{-10} sec, and not 10^{-22} or 10^{-23} sec, like the "resonons", for instance.

Consequently, the law of conservation of strangeness holds only approximately and not rigorously like the law of conservation of electric charge.

Speaking of the electromagnetic interactions, which occupy an intermediate position between the strong and weak interactions, it must be also remembered that many of the particles possess, in addition to an electric charge, also a magnetic moment. Thus the electron and the positron are "magnetized", and their magnetism is mainly caused by their intrinsic spin, i.e., they behave as rotating charges. Part of their magnetism is caused by additional complex "vacuum" interactions with the electromagnetic field and the electron-positron field. The extra effects are called vacuum interactions because they refer to virtual fields and particles and not to concretely observable entities. These concepts are highly sophisticated, but there is really nothing extraordinary about them. For instance, an old and familiar concept is that of the electromagnetic field associated with charges. Now if a charged particle is thoroughly "shaken up"—say, it is made to collide with another particle or given a twist in a magnetic field—then part of the field surrounding the particle will detach itself and be emitted as a photon. In a similar way, it has been found that the particles are surrounded not only by an electromagnetic field but also by a field of electron-positron pairs.

As a result, when charged particles collide it is possible that instead of an electromagnetic field quantum being emitted, an electron-positron pair is produced. In a similar manner the baryons are surrounded by a mesic field which is radiated in the form of pions or kaons. It is noteworthy that when highly energetic nucleons and hyperons collide, several short-lived mesons are produced at once. Speaking of magnetism, we may note that the muons, protons, neutrons, and hyperons are also magnetized. The magnetism of the muons is in all respects similar to the magnetism of the electrons. The magnetic moments of the proton and the neutron are conditioned to a large extent by the magnetism of the π-meson cloud which goes into the structure of these particles.

Apart from the "ordinary" elementary particles, researches in the last few years have uncovered a number of unusual quasi-particles, which might, for brevity, be designated as "resonons" since they appear for the most part as resonances in the scattering of particles (resonance maxima in the effective cross sections). Thus, for instance, nucleons were found to have an excited state N* with the charge $+2e$, which decays after a very short time, like the other resonons, with an average lifetime of about 10^{-22} sec only.

If we adopt the common procedure of expressing the mass or the self-energy of a particle in electron-volts, we have for the energy of an ordinary nucleon 938 Mev, while the energy of N* is 1238 Mev. Further nucleon resonons have been found, denoted by N**, N*** and N****, with masses of 1510, 1680, 1900 Mev, respectively (in round, not yet accurate figures).

Hyperon resonons Y_1^* (1385 Mev) have been discovered, which very rapidly decay according to the scheme:

$$Y_1^* \rightarrow \Lambda_0 + \pi,$$

and also resonons Y_0^*, Y_0^0, and Y_0^{**}, with masses of 1405, 1520, and 1815 Mev, respectively. Resonons have also been discovered in the range of K and π mesons, with the decay schemes:

$$\rho \rightarrow 2\pi \quad (767 \text{ Mev})$$
$$\omega \rightarrow 3\pi \quad (780 \text{ Mev})$$
$$\eta \rightarrow 3\pi \quad (550 \text{ Mev}).$$

It turned out that the resonons ρ could be split into two states.

The ω resonon was the first of this category of quasi-particles to be discovered, by Alvarez (Berkeley). These formations are so short-lived that there is still no way to record their tracks. By analyzing the annihilation of protons and antiprotons, however, it has been shown that the mesons produced as a result (in batches of 5 as an average) are not all the same. Three of them are produced by the decay of some single intermediate particle, called the ω particle. In a similar manner, when protons are irradiated with γ photons, i.e., in a photonuclear reaction, η resonons are produced (the 1962 experiments in Frascati):

$$\gamma + p \rightarrow \eta + p$$
$$\eta \rightarrow \pi^0 + \gamma$$
$$\eta \rightarrow \gamma + \gamma,$$

The η particles may decay either into three pions, or else emit some γ photons. It thus appears that the strong coupling may cause the π and K mesons to "stick" to each other, or to nucleons or hyperons, which leads to the formation of resonons.

In many respects the resonons are similar to "excited" elementary particles—they possess a definite spin, isospin, and parity; on the other hand, they are in a way similar to systems of coupled particles. A task of prime importance is the thorough investigation of the resonons together

with the old, well-behaved particles. The discovery of the resonons has complicated matters, and shows once again the inexhaustible content of matter; at the same time, this will surely provide the means of solving some central problems in our understanding of the inner structure of particles and the ways in which they are related, and bring us a little closer to the formulation of a unified interpretation of all the kinds of matter as we know it.

In order to throw things into their proper historical perspective, let us recall that the new elementary particles were first discovered in the laboratory (the electron, the proton, and the neutron), successively in 1897 (J.J. Thomson), in 1911 (E. Rutherford), and in 1932 (J. Chadwick). Following this, particles were discovered in cosmic rays, specifically primary particles (mainly protons, but also deuterons and nuclei of helium and other elements) with tremendous energies, ranging in the vicinity of 3 billion electron-volts (as observed in the middle latitudes); at that time terrestrial accelerators did not yield such energies. Detected in cosmic rays were the positron (1932, Anderson-Blackett-Occhialini), the μ mesons (1935, Anderson), the pions (1947-1950, Powell), some of the K mesons or "kaons" (1941-1947, Leprince-Ringuet, O'Ceallaigh, and others), and some of the hyperons, viz. Λ, Σ^-, Σ^+, Ξ^- (from 1947 on, Rochester and Butler, Levi-Setti, and others). Later it was possible to obtain high particle fluxes by means of powerful proton accelerators and to discover new particles ($\bar{p}$, $\bar{n}$, K^0, $\overline{K}^0$, Ξ^-, $\bar{\Sigma}^-$, $\bar{\Sigma}^+$, $\bar{\Sigma}^0$, ν_2) and the resonons.

In particular, in 1960 were discovered all the members of the antisigma-hyperon family, viz., the particles $\bar{\Sigma}^0$ (the Alvarez group in Berkeley, U.S.A.), $\bar{\Sigma}^-$ (the Van Ganchan group, and V.I. Veksler in Dubna), $\bar{\Sigma}^+$ (the Amaldi and Manfredini group in Rome, in the analysis of photographic plates irradiated at Berkeley).

In order to give a picture of the efforts being devoted to probing into matter, let us list the most important accelerators operating in the world today, starting with the proton machines: we have the American "Cosmotron", of 3.5 Bev; the American "Bevatron", of 7 Bev; the Soviet machine of 10 Bev at Dubna (with an electromagnet weighing about 30,000 tons and weak focusing); and the French installation "Saturne", of 2.5 Bev. In 1960 a record-breaking proton accelerator, of 28 Bev (with a magnet weighing only about 3000 tons, strong focusing), was put into operation in Geneva, at the European Organization for Nuclear Research (CERN). A similar accelerator, of 33 Bev, was put into operation in 1962 at Brookhaven.

In 1961 the Soviet 7 Bev proton accelerator (strong focusing) was built in Moscow, and it will serve as a model for a proton machine of 50-70 Bev! Machines of up to 1000 Bev are now being planned.

Certainly further advances in the detection of new particles and resonons and of their properties may be expected from the most powerful accelerators, and not only from the proton synchrotrons but also the electron synchrotrons.

To this point we have been discussing only circular proton accelerators, in which the protons are pushed to high speeds by a combination of electric and magnetic fields. Let us now list the existing top-energy electron accelerators. There are two machines in the U.S.A., at the California Institute of Technology and at Cornell University, and a high-flux machine at Frascati, near Rome, imparting to the electrons energies in excess of 1 Bev (1100-1200 Mev). In the fall of 1962 an electron synchrotron of about 2 Bev was put into operation, which is planned to be brought up to 6 Bev

(U.S.A.). In addition, there is a linear electron accelerator of 1 Bev at Stanford University (U.S.A.), where construction has also been started of a high-flux linear electron accelerator, two miles long, with an energy of about 30 Bev.

The proton accelerators have made it possible to further considerably our knowledge of the nature of the strong interactions among nucleons, hyperons, and mesons. On the other hand, by scattering high electron fluxes from a linear accelerator on protons and deuterons, Hofstadter was able to explore for the first time the structure of the elementary particles, measure the size of the proton and the neutron ($r = 0.8 \cdot 10^{-13}$ cm), and even determine the way in which the charge is distributed within them. This is essentially a new development of the methods employed by Rutherford, who used helium nuclei to probe into the atom and thus discover its core, the atomic nucleus.

Some promising experiments were performed at Frascati in 1961-62. Accelerated electrons were extracted from the accelerator and let into a storage ring, where they kept circulating with energies of several hundred Mev for about 2 days. By the same means it was also possible to store up fast positrons and even to create for the first time opposed beams of electrons and positrons. The resultant number of particles, however, was much too small to produce observable collisions, whose analysis is so important for determining the size and structure of the electron and the positron. Protons and π and K^- mesons could not be used to determine the structure of particles, because when they come close to each other fresh particles are generated by the strong interaction; electrons, on the other hand, can smoothly "burrow" into the proton and undergo deflections by the electric forces stemming from the charge distribution within the particle. An accumulator for electrons was recently built in Novosibirsk.

Let us now pause to consider a very interesting phenomenon detected in circular accelerators, which involves the emission of electromagnetic waves by relativistic electrons moving at nearly the speed of light.

This special kind of radiation, of "radiating electrons", also known as "synchrotron" radiation, is the only instance of light emission that does not involve the collision of electrons with matter, i.e., with other particles. In this case the relativistic electrons may be pictured as moving at such high accelerations that the electromagnetic field cannot "keep up" with them and detaches itself, i.e., is emitted. In the energy range of tens to hundreds of Mev the maximum of this radiation lies in the visible region. This unusual type of radiation, visible to the naked eye, was discovered by Pollack in 1944, thus bearing out the theoretical predictions of Soviet physicists Ivanenko, Pomeranchuk, Artsimovich, and Sokolov. The electrons lose a considerable part of their energy by intense synchrotron radiation, and that sets a practical limit to the energies at which circular electron accelerators, for instance, the betatrons (Kerst) and their variations, the synchrotrons (V.I. Veksler, McMillan), can be operated.

Photographs have been taken of beams of radiating electrons. At F.A. Korolev's laboratory a detailed study was made, on the synchrotron of the Academy of Sciences of the USSR, of the spreading of an electron beam with the increase of energy, owing to quantum oscillations of the orbits. As has been predicted by Sokolov and Ternov, at very high energies account has to be taken of the recoil experienced by the electrons when they emit photons.

At Frascati the emission of a single electron has been recorded photographically, i.e., the electron itself was made visible, rather than its tracks, which are seen in cloud chambers or photographic emulsions. We may note that the same kind of "synchrotron" radiation is emitted by fast relativistic electrons in interstellar and stellar magnetic fields and under other astronomical conditions.

In the latter case the radiation is of much longer wavelength and is received as radio emission from stars, galaxies, etc. Synchrotron radiation also plays a part in plasma, where there are similarly relativistic electrons moving in a magnetic field (Trubnikov).

Improvements in detection techniques (such as protracted irradiation of plates at high altitudes by means of planes and rockets, the launching of artificial satellites, the use of stacks of photographic emulsion measuring some cubic meters, etc.) will certainly provide new means of using cosmic rays for discovering particles and studying their properties. The cosmic rays involve processes of stupendous energies of the order of 10^{16} to 10^{18} electron-volts, which are not likely to be attained by terrestrial accelerators in the near future, even though there is some promise in the process of accelerating particles by means of self-regulation (Mints, Petukhov in Moscow), by means of intense laser radiation, and by accelerating plasmoids (V.I. Veksler), etc.

It is an extremely complicated matter to discover a new particle, as was once the case with the discovery of a new chemical element, or, at a different time, of a new radioactive isotope. Thus, it has happened that after some particles had been "discovered" they had to be "undiscovered" later. This was the case with the now defunct varitrons and some heavy mesons, thought to exist in the mass range of 1000-1400 m, which later proved to be none other than the K meson with a basic mass of 966 m. Preliminary data on D-meson tracks (Van Ganchan in Dubna, 1959) prompted a reexamination of the old material on particles with masses of 1200-1500 m in the hope of discovering perhaps some rare D-meson tracks. They were, in fact, never found.

A.I. Alikhanyan and his coworkers reported a flux of particles with a mass of approximately 550 m (about 1% of the number of μ mesons) observable in cosmic rays, but no such evidence has been uncovered in the experiments performed by Conversi (Rome) and in some other laboratories.

III. PARTICLE CLASSIFICATION. ATTEMPTS TO CREATE A UNIFIED THEORY OF MATTER

Let us construct a table of elementary particles (including the resonons), arranging them essentially by order of increasing mass (similarly to the way Mendeleev arranged the chemical elements by order of increasing atomic weight), and then segregate them into families, in accordance with current views. The mass or self-energy of a particle is ultimately its most significant characteristic, as it is for a nucleus and an atom, as well as a planet or a star.

Let us now pause to examine the fundamental, irreducible properties of particles that are known. An important property after the mass is the spin of the particle, i.e., its intrinsic angular momentum. In terms of

spin the particles fall into two distinct categories: the fermions, which have half-integral spin and are subject to Pauli's exclusion principle and to Fermi statistics, and the bosons, which have integral spin and obey the Bose statistics. The spin of a particle defines also the number of components of the corresponding wave function. Thus, for instance, in the case of a photon (spin $S=1$, in units of $h/2\pi$) we have a vector wave function with three independent components; for the graviton ($S=2$) we have a wave function in the form of a symmetric tensor of the second rank (10 components, 5 of them independent); for the π and K mesons ($S=0$) we have a single-component wave function; finally, for all the fermions ($S=1/2$) the wave function will be a spinor (of the Cartan type, or a tensor of rank one-half), in the general case with four components (Dirac-type bispinor); only in the case of the electron-type neutrinos ν and, apparently, the other, muon-type neutrinos ν', is it sufficient to take a 2-component spinor (of the Weyl type). It is further necessary to take into account the parity of the wave function, defined by the behavior of the function under a mirror reflection of the coordinates, or respectively under a time reversal. The wave function of the π and K mesons then turns out to be a pseudoscalar and not a scalar (also characterized by a single component). A scalar and a pseudoscalar behave in the same way under all continuous transformations of the coordinates (and of time), such as rotation and Lorentz transformations, but under mirror reflections a pseudoscalar changes sign, whereas a scalar remains invariant.

Up to this point we have been discussing the "old" properties of particles and their behavior in space-time. The fundamental characteristics of space-time determine the invariance properties and the principal conservation laws, viz., 1) the homogeneity of space leads to the invariance of the field equations (and the corresponding Lagrangians) with respect to translations, and to the law of conservation of momentum; 2) the homogeneity of the time dimension leads to the law of conservation of energy; and 3) the isotropy of space leads to the invariance with respect to rotation and to the conservation of angular momentum.

The transformations of 3- and 4-dimensional translations and rotations and the corresponding conservation laws have been known for a long time; invariance with respect to mirror reflections of the coordinates (i.e., the equivalence of left and right) and with respect to time reversal was also well-known, but the corresponding laws of conservation of the "parity" of the wave function were developed, of course, only after quantum mechanics had come into being, in 1924-1927. In the middle of the fifties it was found (thanks to the work of Lee, Yang, Wu, and others), however, that space parity (P) is conserved only in the strong, but not in the weak, interactions. What is conserved at all times is a composite quantity, the "combined parity", equal to the product of P and the charge parity C. Without going into detail, we may describe the basic operation involved not as a simple transition into the mirror world (since in fact mirror symmetry does not always hold), but rather as such a transition coupled with a change of sign of the charges (i.e., together with charge conjugation, or particle-anti-particle conjugation). We can see, therefore, that it is impossible to remain within the framework of ordinary 4-dimensional space-time with the corresponding conservation laws, and that it is necessary to appeal to new particle properties and new conservation laws in order to understand the phenomena involved. The resultant new quantum numbers provide a

means of classifying the particles more accurately than can be done in terms of spin and parity alone.

For instance, in terms of the old properties that are associated with ordinary space-time, all the fermions are identical, whereas it is a fact that there are significant differences between the hyperons, the nucleons, the muons, the electrons, and the neutrinos.

We have previously mentioned some new characteristics currently employed for the classification of particles: the baryon number N and the lepton number l (sometimes referred to as "charges"), the isotopic spin I, and the strangeness S. The baryon number of all the nucleons and hyperons (proton, Λ_0, etc.) is $N=+1$, and for the antiparticles (antiproton, antineutron, Λ_0, etc.) it is $N=-1$. In a similar manner, the number l is applied to the leptons (the ν and μ particles have not yet been definitively correlated with it). The N and l numbers may be called together the fermion numbers of the particles. Accordingly, a baryon can transform into light particles only in the presence of an antibaryon, for example $p+\bar{p} \rightarrow 5\pi$, but the proton cannot decay on its own into pions and positrons. According to our present state of knowledge, N and l are always strictly conserved individually. Some preliminary empirical considerations pointing to nonconservation of the number of baryons have been put forward by Wheeler, in connection with the possible upper limit for stellar masses. We may note here that the nonconservation of the baryon number could be theoretically founded on the description of particles by "anomalous" spinors (Brodskii and Ivanenko). The isospin, on the other hand, is conserved only in the strong interactions, but not in the electromagnetic or weak interactions. Strangeness is also conserved only in the strong interactions. These conservation laws are correlated with invariance with respect to the corresponding transformations in isotopic space, viz., rotations in the case of isospin conservation, and phase transitions (or gauge transformations) in the case of conservation of the baryon or lepton number. The conservation of ordinary electric charge, i.e., of current, also follows from phase, or gauge invariance. As a result, the transformation and conservation laws now involve not only ordinary space but also isotopic space, in addition to various phase transformations of the wave function.

The concept of isotopic spin was introduced by Heisenberg, when modern nuclear physics was still in its infancy, in order to describe the family of nucleons. Assuming that the basic nucleon has the isospin $I=1/2$, its projection I_3 may assume the two values $+1/2$ and $-1/2$; one is made to correspond to the proton ($I_3 = 1/2$) and the other to the neutron ($I_3 = -1/2$). In addition, there are the two antiparticles $\bar{p}$ and $\bar{n}$.

The π meson has the isospin $I=1$, whose three projections correspond to the three pions (i.e., two charged and one neutral; thus $I_3=+1.0, -1$). The π^+ and π^- mesons are the antiparticles of each other. In reactions produced by the strong coupling the isospin of the system and the third component are conserved. The isospin of the Λ_0 hyperon is 0, which indicates that there are no other members in the family, though there is still an antiparticle; the isospin of the Σ hyperons is equal to 1 (a family of three particles, together with three antiparticles); the isospin of the Ξ hyperons is equal to $1/2$ (two components); the isospin of the K mesons is apparently equal to $1/2$ (two components, together with their antiparticles).

As we see, the number of possible particles is doubled because of the antiparticles, with the exception of the neutral pions and photons which have

no antiparticles (or rather, for which the particles and antiparticles are identical). It has not yet been definitely ascertained whether isospin or a similar concept applies to the leptons; they might possibly form a quadruplet (e^-, ν_1, ν_2, μ^-), supplemented by the quadruplet of antiparticles (e^+, $\bar{\nu}_1$, $\bar{\nu}_2$, μ^+), or perhaps the doublet of muons (μ^+, μ^-) and their neutrinos ν', $\bar{\nu}'$ make a separate set.

As we said before, the kaons and hyperons must be defined by an additional fundamental property, the strangeness, with the particles and antiparticles being assigned a strangeness S of opposite sign (Gell-Mann, Nishijima and Nakano). Strangeness is conserved in strong interactions (for instance, in the coupling between nucleons and pions), and therefore the strange particles produced in the collision of nonstrange particles always appear in pairs, so that their strangeness S_1 and S_2 should cancel out. The conservation of strangeness may be violated when a strange particle decays by weak interaction and transforms into nonstrange particles. There is a fundamental relationship between the ordinary charge Q (in units of e), the third isospin component I_3, the baryon number N, and the strangeness S, which holds for all the pions, kaons, and baryons, viz., $Q = I_3 + \frac{N+S}{2}$. The combination $Y = N+S$ is an important concept, known as the hypercharge.

The family of leptons e^-, e^+, ν, $\bar{\nu}$, μ^-, μ^+, ν', $\bar{\nu}'$ is headed by the photon γ, i.e., the electromagnetic field. We will add to the table the gravitational field (denoted by g) as well, even though, as we said, gravitational waves and their corresponding field quanta (gravitons) have not yet been discovered. In any case, the gravitational field, being associated with the curvature of space-time, must be taken into account in the description of physical reality, and its transverse part, which can take the form of radiation, ought to be in many ways equivalent to ordinary matter. It is predicted that the graviton will have no rest mass and that its spin will be $S=2$ (units of $h/2\pi$).

After having segregated all the known particles into groups in accordance with the classification of Gell-Mann and Nishijima and Nakano, with the addition of the leptons, photons, gravitons, and the newly discovered resonons, it would be natural to seek a theoretical foundation for this grouping. The first successful attempt was made in the beginning of 1956 by d'Espagnat and Prentki, who took as a basis a three-dimensional isospace and considered in it not only rotations, which lead to isospin, but also reflections; by means of the latter it was possible to explain strangeness. This procedure describes particles by defining their isotopic properties; it is thus assumed that the three π mesons form a pseudovector in isospace (isobosons), as do the three Σ hyperons, the two nucleons (the proton and neutron) and the K mesons form in isospace spinors of the first kind (isofermions), and the cascade Ξ hyperons form spinors of the second kind (anti-isofermions), differing from the former only under inversions (by the sign) but not under rotations or Lorentz transformations. (Spinors are wave functions of the Dirac type, describing the particles of spin $1/2$, they may be said to be half-vectors, or square roots of vectors, that is to say, tensors of rank $1/2$.)

The correct value for the hypercharge of every particle is then obtained by subtracting the anti-isofermion number from the isofermion number.

It has been predicted by Gell-Mann that in principle particles with $S=3$ may exist. However, the d'Espagnat-Prentki theory does not allow for a strangeness larger than 2, and this is for the time being in full agreement with experimental data.

The discovery of the new particle properties, isospin, strangeness, and the baryon and lepton numbers, and the resultant classification of particles, made in 1955-1956, have been major advances in particle physics. To those should be added the very recent discovery of the groups of "resonons", the second type of neutrinos, and the neutral anti-Ξ particle.

We should pause to consider briefly the further development of this problem, however, in order to appraise the shortcomings in the system of Nishijima, Gell-Mann, and d'Espagnat-Prentki and to outline the prospects that look most promising in this particular field.

The inadequacy of the given system is clearly exhibited by two facts. First, it does not take into account the leptons and photons and it leaves out gravitation altogether. Second, the systematization does not account for the similarity displayed by all the baryons in their interactions with π and K mesons. All the independent coupling constants of the nucleons and hyperons with π and K mesons have been empirically shown to be virtually the same, in fact. As a result, a number of more general theories have been produced.

In some of the theories the three-dimensional isospace is generalized to a four-dimensional space, mostly taken to be Euclidean (Salam, Polkinghorne, Schwinger, etc.). Some authors, however, use pseudo-Euclidean space. Four-dimensional isospace provides a more unified treatment of particles. Thus, for instance, the Λ and the three Σ hyperons are characterized by a single four-dimensional isotopic pseudovector; it then becomes clear that the coupling constants of the Λ and Σ hyperons with pions are actually identical, and not independent as in the earlier three-dimensional system. Schwinger's system classifies not only the mesons and baryons, but also the leptons; thus e_-, ν, μ_0 form an isotriplet; the photon proves to be a member of a new triplet family, whose other two charged components are not yet known, but are only theoretically predicted.

Schwinger's theory also predicts a fourth π meson (a similar particle, alternatively called a ρ, σ, or $\pi^{\circ\circ}$ meson, was predicted in a number of papers by A.M. Baldin and some others). This particle has still not been discovered either. Several "intermediate" heavy bosons have been also variously proposed, as the particle mediating between the baryons and leptons.

The new bosons have also been predicted by the "compensating field" theory recently developed by Yang and Mills and by Sakurai, a theory held by many physicists (Schwinger, Utiyama, Gell-Mann, Feynman, etc.). This theory once again stresses the point that to each conservation law there corresponds some field—for instance, to the conservation of electric charge there corresponds the electromagnetic field and its quanta, the photons. Analogously to the conservation of baryon charge, of isotopic spin, and of strangeness there must correspond three new types of particles.

These ideas were applied by A.M. Brodskii, G.A. Sokolik and by us to a new treatment of gravitation. It is possible that part of the boson-type vector resonons R_κ are the same as the vector mesons predicted by the "compensating field" theory.

It has been suggested that isotopic and ordinary space might be closely related and that transitions might be possible from one to the other (Ivanenko-Brodskii and G.A. Sokolik, Schwinger, Pais, Vigier, Yukawa); a total reflection could be then defined, as the product of reflections in ordinary and in isotopic space. If one allows for the possibility of transitions

from ordinary into isospace, this means that isotopic properties could go over into ordinary "external" properties. Roughly speaking, if such a hypothesis should prove correct, a particle, for instance, would be able to lose its isospin and acquire ordinary spin instead. The compensating-field theory, which assumes that the phase transitions in isospace are dependent on the ordinary coordinates, also runs along similar lines.

In this connection, Schwinger noted an interesting regularity which applies to neutral bosons: the K mesons do not have ordinary spin, but have an isospin and strangeness; the photons have both ordinary spin and isospin (within Schwinger's scheme); finally, the gravitons should possess spin but no isotopic properties at all. It has been proposed by De Broglie and Vigier that isospace may be considered as an extension of ordinary space inside the particles.

Aside from the O_3 group of rotations in three-dimensional isospace, use has also been made of the groups O_4 (Salam and Polkinghorne), O_5 (Behrends, Fronsdal), O_7 (Tiomno), and even O_8 (rotations in eight-dimensional isospace, Gourski). Out of various other symmetry groups (almost all of which are compact Lie groups, i.e., continuous and described by unitary matrices), theoreticians have recently found particular interest in the groups SU_3 (the group of 3×3 unimodular unitary matrices) and G_2 (the anomalous Cartan group which gives a regular representation of the multiplet components in 14 dimensions). However none of the groups has yet provided a complete classification of the particles and resonons into families. We thus see that in spite of extensive research the problem is far from being solved.

In his summary review of the group-theoretical approach recently presented at the Eleventh International Conference on High-Energy Physics (elementary particles) held in Geneva in the summer of 1962, d'Espagnat expressed particular hopes for the SU_3 and G_2 group treatment, though he also did not consider the problem solved as yet.

A possible method of classification of particles has been proposed, on the basis of which particles of spin $1/2$ (fermions) are associated with a class of spinors that differ only in the way they behave under space or time reflections.

Somewhat earlier Yang and Tiomno proposed using in the same way the reciprocal cofactors 1, -1, $+i$, $-i$, to differentiate between types of mirror-image spinors (classes A, B, C, D), and to associate with them the electrons, neutrinos and μ mesons, respectively. M. Mirianashvili and Gyurshi suggested using in the coalescence method combinations of spinors of different classes, for example A and D, rather than spinors of one class as was done before; unusual boson functions are then obtained, which could perhaps be correlated with the K mesons. A.M. Brodskii, in conjunction with G.A. Sokolik and us, extended these considerations to include a supplementary matrix factor γ_5 for inversions; in that case, if a spinor behaves normally under space reflections, but under a time reflection its wave function is additionally multiplied by γ_5, then this spinor will show an "anomalous" behavior in some relations. It then becomes possible to associate the anomalous spinors with the strange fermions. According to such an interpretation, developed in part by Salam, Taylor, Ognevetskii, and Chou Kuang-chao, the origin of the "strange" properties may be rooted in the anomaly of the spinors, i.e., the way in which their behavior differs under space and time reflections.

After our brief account of the group-theoretical approach, let us turn to the attempt to produce a unified field picture of particles and fields. The basic idea was originated by Louis de Broglie, who proceeded from a simple spinor wave function ψ, describing the particle of least nonvanishing angular momentum, i.e., with spin $1/2$.

If we combine these wave functions under given supplementary conditions, we obtain by such a "fusion" all the other possible wave functions of particles with the spins **0, 1, 3/2, 2...** etc. By combining the two angular momenta $+1/2$ and $-1/2$ we obtain 0, by combining the two angular momenta $+1/2$ and $+1/2$ we obtain 1 (since the spins $\pm 1/2$ may be oriented only parallel or antiparallel), etc. By means of the coalescence method it is possible to combine two Dirac equations, each describing a spinor-type particle (fermion) of spin $1/2$, thus obtaining the Klein-Gordon and the Proca equations, and in the special case of a vanishing rest mass, Maxwell's electrodynamic equations; in principle, therefore, photons could be constructed out of neutrino-antineutrino parts. The ideas of de Broglie's neutrino theory of light have been developed by Kronig, Jordan, and A.A. Sokolov.

A weak point in the coalescence method is the absence of any forces responsible for the coalescence. It fails to explain, for instance, what would cause the neutrino functions to transform into the electromagnetic field. An answer to this has been attempted by a unified nonlinear spinor theory of matter. If one postulates for matter some unique spinor field, then this field would be able to interact only with itself. This leads to the appearance of the nonlinear terms in Dirac's equation, which we introduced for the first time in 1938 and later examined in more detail together with A.M. Brodskii. If it is required that not only relativistic, Lorentz invariance should hold, but also invariance with respect to isotopic rotations (Pauli-Gyurshi transformations) as well as transformations conserving the baryon number (Salam-Touschek transformations), then, as Heisenberg and Pauli have shown, it is necessary to choose the pseudovector term from the set of possible corrections to Dirac's equations. Heisenberg further suggests discarding the mass term, since mass should directly follow from a unified theory. We then obtain the following basic nonlinear spinor equation of a unified theory of matter, which we simply give in symbolic form, without any special explanations:

$$\gamma_\mu \frac{\partial \psi}{\partial X_\mu} + hcl_0^2 \gamma_\mu \cdot \gamma_5 (\bar{\psi} \gamma_\mu \gamma_5 \psi) \psi = 0,$$

where γ_μ are Dirac matrices, h is Planck's constant, c is the velocity of light, l_0 is a new constant denoting the minimal length, and ψ is the spinor wave function.

By formulating some new field-quantization rules, Heisenberg and his colleagues obtained approximate solutions to these equations and derived a basic particle, the nucleon, having a finite mass, and also some mesons with lower masses, which could be associated with π and K mesons. The theory also yields the magnitude of the electric charge and of the Fermi constant of weak interaction between four fermions (for example, the neutron, proton, electron, and antineutrino in beta-decay). Although the theory does not yet provide precise values for the masses of particles or for the coupling constants, it is likely that quite a plausible unified picture of known matter is beginning to take shape. In summing up the proceedings

of the International Conference on Elementary Particles of 1959 in Kiev, I.E. Tamm correctly pointed out that the nonlinear spinor theory looks like one of the most promising trends in particle theory. Some subsequent interesting work on nonlinear spinor theory was done by D.F. Kurdgelaidze, Ya.I. Granovskii, and by Marshak-Okuba and Nambu, who found some points of similarity between this theory and the Bardin-Bogolyubov superconductivity theory. As we mentioned in the first section of this article, according to V.I. Rodichev the nonlinear term in the Dirac equation follows in a straightforward manner if one considers spinor motion not in ordinary flat or curved space, but in a twisted space.

A second version of unified particle theory takes as its point of departure the proposal of Fermi and Yang to consider the π meson as formed from a nucleon and an antinucleon by means of some as yet unknown forces acting at very small ranges, i.e.:

$$p + \bar{p} = \pi.$$

The enormous binding energy involved "swallows up" almost all the mass of the two nucleons, leaving only the mass of the pion. In this case, again, a boson is constructed from two fermions.

Goldhaber proceeded from the p, $\bar{p}$, n, $\bar{n}$, k, and $\bar{k}$ particles. The proposal that proved most successful was Sakata's, further developed by M.A. Markov, B.L. Okun', and others, who took as point of departure the proton, neutron, and Λ particle and the three corresponding antiparticles. It is then possible, by combining these basic particles, to obtain all the pions, K mesons, and hyperons. For example, $\pi^+ = p + \bar{n}$; $K^+ = p + \bar{\Lambda}$. In this case also the nature of the binding or coalescence forces remains unexplained. A minimum of three basic particles is necessary to ensure the presence of the fundamental properties of charge, isospin, and strangeness. Obviously, it is necessary to start off with "rotating", spinor-type particles or fermions, because if "rotation" is not provided to begin with, there is no way of deriving it. These attempts, as the coalescence theory and the nonlinear spinor theory, can be seen to revive in their way the old ideas of Helmholtz and Kelvin, who tried in the middle of the 19th century to construct matter out of hypothetical ether vortices. An attempt was recently made by Sakata and his coworkers at the University of Nagoya to include the leptons in the above model too. They proceeded from the leptons e^-, ν, μ (in the last version of Katayama and others, $\bar{\nu}$) and some "baryon" field B. By combining every lepton with the field B, one obtains the basic heavy particles of the old Sakata model. This also achieves the correspondence between the baryons (p, n, Λ) and leptons (ν, e^-, μ), noted by Marshak, Gamba, and Okuba; the same symmetry is also realized in the nonlinear spinor theory of particles. We may remark that Sakata's scheme follows directly from group-theoretical considerations, within the SU_3 group.

Aside from the group-theoretical, the spinor-field, and the model (Sakata) approaches to the systematization of particles, a new method was developed in the last few years, based on the dispersion relations and the analytical properties of scattering amplitudes, i.e., probabilities of processes.

A number of promising results have been worked out by Goldberger, Nambu, Cini, N.N. Bogolyubov and colleagues, Chew, Frautschi, Yu.M. Lomsadze, A.M. Brodskii, Domokos, and Gribov, and particularly by

S. Mandel'shtam, M. Regge and others, by means of the dispersion relations and calculations based on complex variables of the energy and the linear and angular moments. Briefly, dispersion theory excludes the possibility or the need of describing in detail the interaction and behavior of particles by means of a Lagrangian or a Hamiltonian; it proceeds to treat the scattering probability of particles, for instance, on the basis of the formalism of the scattering matrix S (Wheeler-Heisenberg). The definition of the scattering matrix rests on the most general requirements of invariance, causality, and unitarity. By means of the S matrix the asymptotic scattering of a wave is immediately derived from the incident wave, omitting a detailed description of the interaction. A program of this kind was first formulated by Heisenberg in the forties and was later revived in the form of a dispersion-relation theory. The decisive move was made when it was realized that the S matrix and the scattering amplitudes must be treated as analytical functions of the energy of angular momentum.

The dispersion relations provided the means of drawing up equations for the scattering probabilities of pions and nucleons in various directions, and some important formulas for the scattering probabilities at extremely high energies. The hope has arisen, most clearly expressed by Chew, of linking together the ordinary elementary particles and the resonons, which are all equally treated as poles in terms of the theory of analytic S-matrix functions. This theory gives rise again, though on a different basis, to the concept of excited states of particles. Thus, for instance, the particles in the family formed by the nucleon and the nucleon resonons, R_N: N^*, N^{**} N^{***}, N^{****} , all lie on a single trajectory of Regge poles. The masses of the resonons are obtained given the appropriate spin values. Chew's rather extreme program stands in sharp opposition to the old Lagrangian and all ordinary field-theoretical methods. But in spite of the fact that some of the notable successes of particle theory in recent times have been associated with dispersion theory, analytic properties, and Regge poles, we still have doubts about the possibility of constructing a particle theory divorced from field-dynamic conceptions, as do Schwinger, Heisenberg, Feynman, Sakurai, Nambu, and others, as well. At any rate, this field of inquiry is evolving quite rapidly, mainly due to the development produced by the discovery of the resonons, of new particles, and of many reactions.

In concluding, we must return to gravitation once more. Within nonlinear spinor theory it is in principle possible to derive the gravitons as quanta of a weak transverse gravitational field, though it is doubtful that the total field $g_{\mu\nu}$ can be obtained. On the other hand, by proceeding from various geometrical considerations (particularly, Wheeler's geometrodynamics) it might be possible to derive the electromagnetic field and perhaps other boson fields as well (the π and K mesons), but for the time being there are no chances that spinors will be obtained.

It thus seems that our representation of physical reality must, for the time being, remain dualistic—on the one hand there is space (curved or perhaps twisted) and time, and on the other, intimately connected with them, "ordinary" matter in the form of various elementary particles and "resonons"; the latter might perhaps be excited or compound states of a few basic particles or of some unique (spinor-type) "protomatter".

The graviton (the transverse part or waves of the gravitational field) would occupy an intermediate position, forming some sort of "ripples"

on the fundamental space-time network and being at the same time capable of transforming into ordinary matter.

Modern physics has now at its disposal giant accelerators, recording devices on Earth and in space, and highly sophisticated computers. It is bound to uncover new horizons in our knowledge of matter and the universe, and to contribute to the technical achievements of civilization.

Elementary particles (1962)

Class			Symbol	Particle	Mass	Spin parity	Isotopic spin I (components I_3, I_3)	Strangeness, S
"Fields"			g	graviton	0	2^+		
			γ	photon	0	1^-		0
Leptons	muons	$l=1$, $N=0$	ν	neutrino	0	$\frac{1}{2}$		
			$\bar{\nu}_e$	antineutrino	0			
			e^-	electron	1			
			e^+	positron	1			
		μ	μ^-	mu-minus	206.8			0
			μ^+	mu-plus				
			ν'	mu-neutrino				
			$\bar{\nu}'$	mu-anti neutrino	0			
Mesons	pions	π, $l=0$, $N=0$	π^-	pi-minus	273.2	0^-	$I_3=1$	
			π^+	pi-plus			$+1$ } $I=1$	
			π^0	pi-neutral	264.2		0	
	pion resonons R_π		ω	omega resonon	788 Mev	1^-	0	
			ρ	rho resonon	750 .	1^-	1	
			η	eta resonon	548 .	0^-	0	
			f_0	zeta resonon	1250 .	2		
	kaons	K	K^+	K-plus	966.6 m	0^-	$(+1/2)$	$+1$
			K^-	anti-K-plus (or K-minus)			$(-1/2)$ } $1/2$	-1 } 1
			K^0	K-neutral	974.2 m		$(-1/2)$	$+1$
			$\bar{K}^0$	anti-K-neutral			$(+1/2)$	-1
	kaon resonons R_k		K^*	K-resonon	888 Mev			
			φ_{kk}		1020	0^+	0	
	nucleons	$N=+1$, $S=0$	p	proton	1836.1 (938 Mev)	$1/2$	$(+1/2)$	0
		$N=-1$, $S=0$	$\bar{p}$	antiproton			$(-1/2)$ } $1/2$	0 } 0
		$N=+1$, $S=+1$	n	neutron	1838.6		$(-1/2)$	0
		$N=-1$, $S=-1$	$\bar{n}$	antineutron			$(+1/2)$	0

Continued

Class		Symbol	Particle	Mass	Spin parity	Isotopic spin I (components I_3, I_3)	Strangeness S
Baryons	nucleon resonons R_N	N^*		1512 Mev	$3/2^-$	$1/2$	
				1688 .	$5/2^+$		
				2190 .	?		
		Λ		1238 .	$3/2^+$	$3/2$	
				1650 .	$5/2^-$		
				1920 .	$7/2$?		
				2330 .	?		
	hyperon Y $N=+1$	Λ_0	lamba	2183 m	$\frac{1}{2}^+$	0	-1
		$\overline{\Lambda}_0$	antilambda			0	$+1$
		Σ^+	sigma-plus	2328		$+1$	-1
		$\overline{\Sigma}^+$	antisigma-plus			-1	$+1$
		Σ^0	sigma-neutral	2332		0	-1
		$\overline{\Sigma^0}$	antisigma-neutral			0	$+1$
		Σ^-	sigma-minus	2341		-1	-1
		$\overline{\Sigma}^-$	antisigma-minus			$+1$	$+1$
		Ξ_0	xi-neutral	2566			-2
		$\overline{\Xi}_0$	antixi-neutral				$+2$
		Ξ^-	xi-minus	2580			-2
		$\overline{\Xi}^-$	antixi-minus				$+2$
	hyperon resonons R_Y	Y^*	hyperon resonons	1405 Mev			
		Y^{**}		1520 .			
		Y^{***}		1381 .			
		Y^{**}_0		1815 .			
		Ξ^*		1535	?	$1/2$	-2

REFERENCES

Publications in Russian

Filosofskie problemy sovremennogo estestvoznaniya (Philosophical Problems of Modern Science).— Izdatel'stvo AN SSSR. 1959.

IVANENKO, D. and A. SOKOLOV. Klassicheskaya teoriya polya (Novye problemy) (Classical Field Theory (New Problems)), 2nd edition.— Gostekhizdat, Moskva-Leningrad. 1951.

IVANENKO, D. and A. A. STARTSEV. Klassifikatsiya elementarnykh chastits (Classification of the Elementary Particles).— In: UFN. December 1960.

KOL'MAN, E. V. I. Lenin i noveiskaya fizika (V. I. Lenin and Modern Physics).— Gospolitizdat. 1959.

KUDRYAVTSEV, P. S. Istoriya fiziki (History of Physics), Vols. I and II.— Uchpedgiz. 1956.

KUZNETSOV, B. G. Razvitie nauchnoi kartiny mira (The Evolution of a Scientific World Picture).— Izdatel'stvo AN SSSR. 1955.
KUZNETSOV, B. G. Printsipy klassicheskoi fiziki (Principles of Classical Physics).— Izdatel'stvo AN SSSR. 1958.
LENIN, V. I. Materializm i empiriokrititsizm (Materialism and Empiriocriticism), Collected Works, Vol. 14.
MARKOV, M. A. Giperony i K-mezony (Hyperons and K-Mesons).— Fizmatgiz. 1958.
Nelineinaya teoriya polya (Nonlinear Field Theory). Collection of translated articles by Heisenberg and others, with an introduction by D. Ivanenko.— Moskva, IL. 1959.
Noveishie problemy gravitatsii (Modern Problems in Gravitation). Collection of translated articles with an introduction by D. Ivanenko.— Moskva, IL. 1961.
NOVOZHILOV, Yu. V. Elementarnye chastitsy (Elementary Particles).— Fizmatgiz, Moskva. 1963.
Ocherki razvitiya osnovnykh fizicheskikh idei (Outlines on the Development of Fundamental Ideas in Physics), Collection of Articles.— Izdatel'stvo AN SSSR. 1959.
SMORODINSKII, Ya. A. Elementarnye chastitsy (Elementary Particles).— In: Narodnyi universitet kul'tury, No. 1. Izdatel'stvo "Znanie." 1962.
SOKOLOV, A. A. Elementarnye chastitsy (Elementary Particles).— Izdatel'stvo MGU. 1962.
SOKOLOV, A. and D. IVANENKO. Kvantovaya teoriya polya (Izbrannye voprosy) (Quantum Field Theory (Selected Topics)).— Gostekhizdat, Moskva-Leningrad. 1952.
SOKOLOV, A. A., Yu. M. LOSKUTOV, and I. M. TERNOV. Kvantovaya mekhanika (Quantum Mechanics).— Uchpedgiz. 1962.
Tezisy I Sovetskoi gravitatsionnoi konferentsii (Papers of the First Soviet Conference on Gravitation).— Izdatel'stvo MGU. 1961.

Publications in Other Languages

WHEELER, J. A. Geometrodynamics. Neutrinos, Gravitation, and Geometry.— New York, Academic Press. 1962 [Russian translation. 1962.]

Yu. S. Vladimirov

NEW DEVELOPMENTS IN THE STUDY OF GRAVITATION

At the end of June 1961 the First Soviet Conference on Gravitation was held in Moscow. The conference was convened by the Physics Faculty of Moscow State University [MGU] and the Shternberg State Astronomical Institute [GAISh]. At the time of the conference, significant advances were being made in gravitational research, and physicists were beginning to have at their disposal more and more experimental means for the investigation of gravitation. Artificial satellites and space rockets, the latest techniques of nuclear physics (utilization of the Mössbauer effect, i.e., of recoilless gamma rays), the development of atomic and molecular time standards ("clocks"), and finally the advances made in radio physics, all combined to make possible an experimental check of the effects predicted by the gravitation theory based on the general theory of relativity, both under terrestrial conditions and on the scale of the entire solar system.

It should be noted that at this time considerable changes were also occurring in the theoretical methods used to study gravitation. In recent studies of the general theory of relativity, extensive use was made of the methods of relativistic quantum field theory (quantization of the gravitational field). Moreover, the relation between the general theory of relativity and elementary-particle theory was investigated (the transmutation of gravitation into ordinary matter and vice versa, the existence of antigravitation, etc.), and the group-theoretical approach was applied to gravitation (the compensating-field interpretation of the gravitational field). A number of attempts were also made to go beyond the traditional framework of Einsteinian geometry. Thus, such problems as the variation of the gravitational constant and the introduction of generalized geometries were posed, both in order to provide geometrical interpretations of the already known fields and to use these interpretations to predict new fields and physical effects (the twisted field). Finally, certain studies offering a fresh treatment of Einstein's original equations had appeared.

These factors made it imperative to hold an All-Union Conference on Gravitation. The conference was intended to provide an overall view of current gravitational research, to appraise the results obtained, and to promote further studies of the general theory of relativity.

Many scientific and educational institutions of the USSR were notified of the forthcoming conference. The number of participants and reports was more than three times that anticipated by the organizers. The scientists participating in the conference came from many Soviet cities and towns, including Leningrad, Kazan, Tartu, Minsk, Kharkov, Dubna, Kiev, Yerevan, Samarkand, Sverdlovsk, Krasnodar, Odessa, Poltava, and Tbilisi.

The following major institutions of physical science in Moscow were represented: Moscow State University, the N. E. Bauman Moscow Technical College [MVTU], the P. N. Lebedev Physics Institute of the USSR Academy of Sciences, the S. I. Vavilov Institute of Physical Studies, the Institute of Theoretical and Experimental Physics, the Institute of Earth Physics, the Institute of Chemical Physics of the USSR Academy of Sciences, the Aeronautical Institute, and many others. Scientists from the major Soviet laboratories at Dubna (Joint Institute for Nuclear Research) [OIYaI] also participated actively.

Over 900 reports were presented at the conference. These were divided according to subject matter into several groups, and each group of problems was discussed at a separate session. Seven individual sessions were held. Two of these were devoted to classical gravitation problems, and one session each was devoted to the following subjects: problems in the quantum theory of gravitation; non-Riemannian generalizations of geometry; cosmology; the fundamental problems of gravimetry; and experimental investigations.

Just before the opening of the conference, a small symposium was arranged for the junior participants, at which the following survey lectures were delivered: "The Energy-Momentum Tensor", by Dr. N.V. Mitskevich (Samarkand); "Cosmological Models", by Dr. A.L. Zel'manov (GAISh and MGU); and "Relativistic Hydrodynamics", by Prof. K. P. Stanyukovich (MVTU). During the conference itself, Prof. Ya. A. Smorodinskii (OIYaI, Dubna) gave a lecture entitled "Neutrino Physics".

The conference sessions were well attended (usually 150 to 200 people were present), and lively debates constantly took place, developing at times into heated discussions.

The conference opened with an introductory address by the representative of the organizing committee, Prof. D. D. Ivanenko, who reviewed in brief the aims of the conference. The conference then proceeded to its first topic of discussion, "The Classical Theory of Gravitation".

The first report was read by Prof. A. Z. Petrov (Kazan University), who gave an account of his fundamental studies of gravitation theory (one of the main contributions to this field during the last decade). A detailed account of these studies cannot be given here; we should mention, however, that Petrov has classified the solutions of Einstein's equations according to three mutually irreducible types. It was shown that practically all the solutions known at that time could be reduced to the first type, and that the requirement of a flat space at infinity applies only to this type (this requirement being intrinsically invalid for the other two types). Petrov's studies stimulated considerably the search for new solutions, and now solutions of all three types have been obtained.

New solutions of Einstein's equations were analyzed and discussed in the contributions of N. V. Mitskevich (Samarkand), A. A. Koppel' (Tartu), V. S. Brezhnev (MGU), and Prof. N. M. Petrova (Alma-Ata).

The Schwarzschild solution is known to have a singularity at certain values of r_0, the gravitational radius. The physical interpretation of this problem was dealt with in the reports of the young theoreticians V. A. Unt (Tartu), I. D. Novikov (MGU), and Yu. A. Rylov (MGU).

Some interesting studies of particle motion near the gravitational radius were discussed by S. L. Galkin (MGU). These investigations are of particular interest in connection with the prediction recently made by

V. A. Ambartsumyan and G. S. Saakyan concerning the existence of hyperon stars (stars consisting mainly of superheavy hyperons) having radii comparable to the gravitational radius.

The second session on the first day of the conference was combined with a session of the Sixth All-Union Conference on Extragalactic Nebulae, which was being held concurrently. Reports were read by E. M. Lifshits, V. V. Sudakov, and I. M. Khalatnikov (Institute for Physical Problems, USSR Academy of Sciences), M. F. Shirokov (Moscow), I. Z. Fisher (Minsk), R. I. Khrapko (Moscow), and A. L. Zel'manov (GAISh). These contributions examined various aspects of the expansion of the universe and the problem of a singular point in time (the beginning of the expansion).

Ya. A. Smorodinskii (Dubna), B. M. Pontecorvo (Dubna), and V. M. Kharitonov (Yerevan) presented reports discussing the role played by neutrinos in the structure of the universe (see V. S. Brezhnev's article in this collection).

The discussion of the classical theory of gravitation was resumed at the morning session of 28 June. The energy of the gravitational field, or rather the energy-momentum tensor of the field, was discussed by N. V. Mitskevich (Samarkand), I. I. Gutman (Uzbek SSR), M. E. Gertsenshtein (Moscow), and others. Although some interesting findings were reported by these investigators, this difficult problem is unfortunately still far from being solved.

The participants of the conference expressed considerable interest in the possibility of the existence of antigravitation (this term denotes repulsion instead of attraction between bodies). D. I. Blokhintsev considered the paradoxes which would be associated with the nonconservation of gravitational energy if antigravitation did exist. The question was also discussed in the report by Prof. Ya. P. Terletskii (MGU).

Podgoretskii, Okonov, and Khrustalev, of the Joint Institute for Nuclear Research, proposed an experiment designed to detect antigravitational properties in antiparticles. This experiment would use vertical beams of K mesons, whose decay is strongly affected by the magnitude and sign of the mass. At the same session, some reports on gravitational waves were also read. As a spokesman for himself and his colleagues, (A. M. Brodskii and D. D. Ivanenko), G. A. Sokolik discussed the new "compensating-field" treatment of the gravitational field. According to this new approach, which is based on the ideas recently developed by Sakurai, the parameters of the Lorentz group of transformations are considered to be functions of the coordinates. This leads to the appearance of some additional terms in the Lagrangian and in the equations of motion. If the Lagrangian is to remain invariant under Lorentz transformations, some new field must be introduced which would transform from point to point in such a way as to compensate for the extra terms. It was shown in the report that the compensating field must be the gravitational field. The authors are of the opinion that the new approach should enable a re-examination of certain problems in the general theory of relativity and should facilitate their solution.

The evening session of the second day of the conference was devoted to a discussion of non-Riemannian generalizations of geometry. Under the very general requirements imposed upon geometry, there are 27 possible types of differential geometries, of which the Riemannian geometry

employed in the general theory of relativity is a particular trivial case. At this session the physical implications of the spaces related to these geometries were considered, particularly with reference to spaces possessing a twist. This problem was discussed in the reports of A. E. Levashov (Kiev), O. S. Ivanitskaya (Kiev), V. I. Rodichev (Moscow), and Yu. S. Vladimirov (MGU). The report read by Rodichev was quite interesting; he demonstrated that if Dirac's fundamental equation is considered in twisted space, a nonlinear term of the Ivanenko-Heisenberg type appears. Thus, in the equation describing the basic elementary particles and the "protomatter" which apparently forms a basis for the entire world, any particle is shown to interact with itself, the interaction being precisely of the type established by Ivanenko and Heisenberg on the basis of other considerations. Similar subjects were also considered in the reports of D. F. Kurdgelaidze (MGU), S. F. Shushurin (MGU), and V. B. Lysikov (Kharkov), dealing with new exact solutions of nonlinear equations of this kind. Also at this session, A. Z. Petrov presented a brief survey and analysis of some unified field theories, and V.S. Brezhnev presented a study of Finslerian geometry.

The fifth session was devoted to a relatively new field of gravitational research, the quantum theory of gravitation. The report of D.I. Blokhintsev (Dubna) dealt with fluctuations of the metric, which are especially significant at small distances (of the order of 10^{-32} cm). The possibility of the transformation of particle-antiparticle pairs into transverse quanta of the gravitational field, and vice versa, was examined in the report presented by D. D. Ivanenko (MGU). The author suggests that such processes may be of considerable importance in cosmology. An interesting report was read by V. G. Kadyshevskii (MGU), giving a geometrical interpretation of weak interactions.

The study of weak interactions of particles should indicate a new geometry of space-time, with discrete properties at small distances (of the order of 10^{-17} cm), in the same way as the general theory of relativity indicates the curvature of space-time as a result of the presence of gravitating masses. The mechanism of gravitational interaction involving the emission of gravitational field quanta, or gravitons, by gravitating bodies was considered by Prof. K. P. Stanyukovich (MVTU), who constructed a theory of gravitational interaction based on the hypothesis of emission and absorption of the actual gravitational field quanta (gravitons). This report provoked a lively debate.

One of the high points of the conference was the session at which experimental verification of the general theory of relativity was discussed. This session was held at the Joint Institute for Nuclear Research in Dubna. A very interesting report, presenting a critical survey of all known observations of the Einsteinian deflection of light rays near the Sun, was read by A. A. Mikhailov, Corresponding Member of the USSR Academy of Sciences.

Corresponding Member of the USSR Academy of Sciences V. L. Ginzburg (Lebedev Institute of Physics) gave a review of the experimental studies of gravitation which are possible using artificial satellites. A basic study entitled "The Possibility of Studying some Relativistic and Cosmological Effects by means of Molecular and Atomic Frequency Standards", which was the work of five collaborators at the Lebedev Institute of Physics

(N. G. Basov, O. N. Krokhin, A. N. Oraevskii, G. M. Strakhovskii, and B. M. Chikhachev) was presented by G. M. Strakhovskii. Atomic and molecular frequency standards are known to be extremely precise, due to the use of the natural frequency of spectral lines as a reference. With the help of rockets and artificial satellites, atomic standards can be carried far away from the Earth, which provides a means of measuring reliably the frequency shift produced in a gravitational field. V. B. Braginskii and G. I. Rukman (MGU) presented an interesting report dealing with a projected experiment for detecting gravitational waves under laboratory conditions. The project proposed by colleagues at the Joint Institute for Nuclear Research, namely that an experiment to detect antigravitational properties in antiparticles be carried out, was brought up again and raised considerable interest. A report was also presented by A. A. Bonch-Bruevich and Ya. E. Kariss (Leningrad), dealing with the possible existence of anisotropic features of gravitation, and describing an experiment for determining the velocity of propagation of gravity.

The last group of subjects to be considered at the conference concerned the basic problems of gravimetry. The reports presented in connection with this were: "The Maximum Accuracy of Modern Gravity Measurements", by P. N. Agaletskii, and "Gravity Observations during a Total Solar Eclipse", by N. P. Grushinskii and M. U. Sagitov (MGU).

A number of the reports discussed the Earth's expansion and the possible connection between this hypothetical phenomenon and gravity, a subject which proved to be rather controversial. The reports which dealt with this were: "The Secular Weakening of Gravity and the Earth's Expansion", by D. D. Ivanenko and M. U. Sagitov (MGU); "Facts in Support of the Expanding-Earth Hypothesis", by V. B. Neiman and I. V. Kirillov; and "Geological Facts Indicating Absence of the Decrease in the Gravitational Constant Assumed by the Jordan-Dirac Hypothesis", by P. N. Kropotkin. Back in the thirties, Dirac and Jordan proposed that the gravitational constant decreases with time. If such were the case, the Earth (as well as any other planet or star) would undergo a gradual expansion. In particular, the fact that some of the continents have matching contours may be explained in this way, provided it is assumed that the Earth was considerably smaller at the beginning of its expansion ($4 \cdot 10^9$ years ago), and that its total surface was then equal to the present area of the continents. The facts adduced in support of this argument were related to the slowing down of the rotation of the Earth and to the presence of cracks in the terrestrial crust. The discussion of this subject eventually developed into an analysis of geological and biological problems.

It should be noted that of the large number of reports presented at the conference only one (that of V. V. Radzievskii) treated gravitation from the pre-Einsteinian point of view. This approach, moreover, was not received favorably by the participants of the conference.

On 1 July, the last day of the conference, a supplementary session was held, so that reports which had not been presented at the main sessions (due to the overcrowded agenda) could be given. Of these, mention should be made of the report by G. E. Skrotskii (Sverdlovsk), dealing with the effect of the Sun on the rotational properties of an electromagnetic field, and the report by I. I. Kogal'nikova giving a historical survey of the evolution of gravitational concepts.

It is safe to say that the conference was successful and timely, and that it indicated where Soviet gravitational research is up to par in comparison with work abroad (the classical theory of gravitation, cosmology) and also where further effort is necessary (the quantum theory of gravitation and experimental studies). In addition, the conference was helpful in preparing Soviet gravitation physicists for the Fourth International Conference on Gravitation, which was held in Warsaw in July, 1962.

In conclusion, the participants of the conference unanimously adopted the following resolutions: 1) to call a Second Soviet Conference on Gravitation in 1963; 2) to publish all the proceedings of the conference; 3) to establish laboratories for the study of gravitational problems in Moscow and Kazan; and 4) to set up a Soviet Advisory Commission on Gravitational Research, for coordinating and promoting further research in this field.

PART TWO
STRUCTURE AND EVOLUTION OF THE UNIVERSE

V.A. Ambartsumyan

GALAXIES AND GALACTIC EVOLUTION

This article will review the main facts of extragalactic astronomy. A correct representation of the outer star systems (galaxies) was obtained only about 40 years ago, so that many basic problems concerning the outer galactic world still remain unsolved. Therefore, it will be advisable to formulate here some of the problems which we consider the most significant for future extragalactic investigations. An attempt will be made to remain within the domain of facts and to devote specific attention to those problems which appear capable of solution with the means now available.

Extragalactic astronomy is closely related to cosmology, the theoretical science which attempts to describe the universe as a whole. Cosmological theories are of definite value, in that they analyze certain solutions of the equations of Einstein's general theory of gravitation and aim at a comparison of these solutions with the properties of the observable portion of the universe. It is a fact, though, that these theories are often used as a basis for gross oversimplifications and wild extrapolations.

The scope of this article does not allow us to analyze these theories or to consider their further development, although it is our opinion that a critical survey of current studies in this field would be very valuable. At the same time, the facts and problems considered below should be relevant to cosmological theories as well.

I. THE MAIN FACTS RELATED TO THE DISTRIBUTION OF MATTER

One of the properties of the world surrounding us is that the bulk of the observable matter is concentrated in stars. Other bodies contain only a small part of the total observable mass.

The most significant fact of extragalactic astronomy is that the great majority of observable stars are members of stellar systems known as galaxies. The dimensions of galaxies and their stellar populations vary within unusually wide limits. Supergiant systems (such as the two brightest galaxies, NGC4874 and NGC4889, situated at the center of the cluster in Coma Berenices) may have absolute photographic magnitudes as high as -22 and may contain hundreds of billions of stars. Dwarf systems, on the other hand (such as the galaxy in Sculptor), have absolute magnitudes of about -11 and apparently only contain several million stars. On the fringes of the dwarf galaxies, moreover, systems with even lower luminosities have

been detected, which may be referred to as subdwarf galaxies. An example of such a system is the galaxy in Capricornus, discovered by Zwicky, which has an absolute photographic magnitude of about -6.5. This system presumably contains at most several tens of thousands of stars. It thus has less than one ten-millionth of the population of a supergiant galaxy and it even contains fewer stars than many of the globular clusters.

The diameters of galaxies usually range between 50,000 parsecs (for the supergiants) and 500 parsecs (for the subdwarfs). Giant and supergiant galaxies (diameters between 5000 and 50,000 parsecs) have high surface brightnesses (over $24^m.0$ per square second of arc) and they have intense concentrations of luminosity toward the galactic center. The dwarf galaxies include objects with high surface brightness as well as objects with low brightness. It is significant, however, that in addition to dwarf systems with high gradients of surface brightness from edge to center, galaxies have also been observed in which this gradient is very low, so that on photographs the system appears as a disk of almost uniform brightness*.

The fact that most stars are members of galaxies is quite significant, if we take into consideration that, as a first approximation, the galaxies constitute isolated systems. The distances between neighboring galaxies are normally many times larger than the diameters of their central, densest regions, although the very tenuous parts of the galaxies, located a long way from the galactic centers, may often interpenetrate. In addition to being topographically isolated, galaxies are also dynamically closed stellar systems. A dynamically closed system here refers to the fact that the motions of the stars in each galaxy are mainly determined by their interactions with the other members of the same galaxy. However, the condition of dynamic isolation is satisfied only to a certain degree of approximation. Mutual disturbances of stellar systems which are close to one another, and eruptions from galactic centers (galactic eruptions will be discussed below), are instances in which the dynamic isolation is more or less violated.

In the same way as stars form into galaxies, the galaxies in turn form larger systems, such as galactic clusters, galactic groups, and multiple galaxies.

Two decades ago the idea prevailed that, in addition to the galactic clusters and groups, there exists a general field in which most of the galaxies are contained (just as in our stellar system there is a general star field impregnated with star clusters and associations). At present,

* The dwarf systems discovered by Shapley in Sculptor and Fornax are examples of galaxies in the Local Group which have low density gradients. The surface brightnesses of these systems are unusually low. Baade subsequently showed that galaxies NGC147 and NGC185 (also in the Local Group) have low density gradients too. This galactic pair has a surface brightness considerably higher than that of the systems in Sculptor and Fornax. Two other members of the Local Group (Sextans B and Leo 2) have intermediate surface brightnesses. These also have very low density gradients. In the Virgo cluster there are a large number of objects with low surface luminosities and low density gradients. Some of these have linear dimensions close to those of medium-sized galaxies. For instance, galaxy ICn3475 has a very low surface brightness and a negligible density gradient, while its diameter is 5000 parsecs. The dimensions of this galaxy thus exceed by far those of similar objects in the Local Group.

It should be noted, nevertheless, that relatively large objects with low density gradients and low surface brightnesses are quite rare. For instance, in the cluster in Cancer the largest galaxy of this kind has a linear diameter of about 2500 parsecs.

however, the existence of such a general field is considered to be unlikely. Nevertheless, as far as high-luminosity galaxies are concerned, it is true to say that for the most part they are members of galactic clusters, groups, and multiple systems.

The observed galactic clusters are divided into two types: globular clusters, with regular, symmetrical distributions of galaxies about the center; and diffuse clusters, in which the galaxies have largely irregular distributions. The populations of globular clusters are mainly made up of elliptical galaxies, while diffuse clusters contain a high percentage of spiral galaxies. On the fringes of diffuse clusters there are galactic groups, such as the Local Group or the groups around M101 and M81.

The galactic groups associated with M101 and M81, for instance, do not actually contain a single elliptical galaxy; they consist only of spiral and irregular galaxies. The galactic group in Sculptor (studied by de Vaucouleurs) contains only galaxies of the Sc type and irregular galaxies. Finally, the Local Group does not contain any elliptical galaxies of high luminosity either, but it does include some elliptical galaxies of low and medium luminosity.

It is interesting to note too that the Local Group essentially consists of two quite small galactic groups, with dimensions close to those of multiple galaxies. The first group comprises our Galaxy, the Large and Small Magellanic Clouds, and apparently a few galaxies of the type of the system in Sculptor as well. The second group contains the Andromeda Nebula with its four companions and M33. However, this division can be considered valid only for galaxies of high and medium luminosity. Dwarf galaxies, on the other hand, may quite possibly be distributed continuously throughout the entire Local Group. It should be added that the total mass of the Local Group is mainly determined by the masses of the two galaxies which are essentially the centers of the above-mentioned two subgroups (M31 and our Galaxy).

In some cases, galactic clusters which have many members occur in twos and threes, and thus form multiple galactic clusters. It was mentioned above that galaxies as a rule represent closed stellar systems. There are cases, however, when the systems are not isolated, and three categories of such objects will now be described.

a) Interacting galaxies. These are cases in which two galaxies are close together, and the presence of one galaxy has a strong effect on the structure of the other. Many examples of interacting galaxies are listed in the atlas of B. A. Vorontsov-Vel'yaminov, who has contributed considerably to the study of these interesting objects. The observed interactions may be explained in two ways: 1) as a result of tidal action, and 2) as a result of the separation of two galaxies which were initially together. In the latter case the "interactions" are considered to be a consequence of the separation process.

b) Pairs of galaxies connected by bridges or bars. Many instances of this have been reported by Zwicky, who has demonstrated that the bars are made up of stars. Jets, or streamers, emanating from the central regions of some spherical galaxies, and containing blue condensations made up of dwarf galaxies, border upon the bars.* It has

* For example, NGC3561 and IC1182 are high-luminosity galaxies which have streamers containing blue condensations issuing from their central regions.

been noted that the streamer joining a large galaxy to a dwarf galaxy also resembles a bar, and in such cases there is little doubt but that the dwarf galaxy detached itself from the central core of the main galaxy. It thus seems more plausible to assume that bridges and bars are in fact the result of a division of a single galaxy into two parts.

c) Radio galaxies. Previously, radio galaxies were assumed to be the result of random collisions between two independent stellar systems, and the energy of the observed radio emission was assumed to come from the collision of the gaseous masses contained in the two galaxies. However, the facts have not supported such a hypothesis. All the data tend to indicate that radio galaxies represent some (possibly very brief) stage in the internal evolution of galaxies of very high luminosity (supergiant galaxies).

The radio-emission intensity of a galaxy is apparently closely connected with the genesis of new intragalactic formations, such as condensations and streamers (which are expelled from the center), spiral arms, and even whole new galaxies. In other words, in some cases a galactic center divides, and a new galaxy forms in the depths of the old one. This is why radio galaxies are often extremely compact systems consisting of an old galaxy and new formations, the latter usually being still embedded in the parent galaxy.

It should be noted that all the types of nonisolated galaxies described above together constitute only a small percentage of the total number of galaxies. There is good reason to believe that such cases of nonisolation occur at a definite stage of galactic evolution (specifically, when new galaxies are formed).

Despite the significant advances which have been made in the study of the spatial distribution of galaxies, there are still many important problems which remain unsolved. Let us now consider some of these.

a) Do galactic clusters as a rule combine to form systems of higher order, such as superclusters or a supergalaxy? Our Local Group is evidently a member of a certain group of clusters whose center is represented by the large cluster in Virgo. This extensive spatial grouping was designated the Supergalaxy by de Vaucouleurs. It measures about 20 million parsecs across. However, we have as yet no evidence for the dynamic unity of this system, or for the existence of any forces capable of sustaining it.

At the same time, it is noteworthy that a study of the distribution of galaxies on the celestial sphere does not clearly reveal any appreciable number of such supergalaxies. When considering this problem, however, two conceivable possibilities should be taken into account: 1) that the distances between supergalaxies are very large in comparison with their diameters; and 2) that these distances are of the same order as the diameters of the supergalaxies.

In the first case, many of these supergalaxies would be distinctly visible against the celestial sphere as isolated formations. In the second case, we would see projected against the sky only a small number of relatively near isolated systems of this kind, and by means of a superficial study it would be difficult to deduce the existence of any distant supergalaxies.

Observations show clearly that the distribution of galactic clusters and groups is nonuniform, and the existence of supergalaxies may explain this to a certain extent. It may be assumed at the same time that we only

observe a few isolated nearby clouds consisting of a large number of condensations. The only thing which has been definitely established is the presence of a large cloud in the southern sky, extending between galactic longitudes of 160° and 240° and having a galactic latitude of -40°. *

These two facts indicate that the second alternative is the correct one, that is, that supergalaxies do exist and that the distances between them are of the same order as their diameters.

Thus, even though the existence of individual supergalaxies seems to be an established fact, there are still certain questions which remain unanswered. For example, it is not known what percentage of the galactic clusters are members of such higher-order systems, or whether both of the known types of clusters (globular and diffuse) exhibit an equally strong tendency toward bunching together. Answers to these questions will be possible only on the basis of more detailed photometric and statistical studies.

b) To what extent do low-luminosity galaxies have the same spatial distribution as high-luminosity galaxies? As we said before, the fact that galaxies concentrate in clusters has been quite well established for high-luminosity objects. Objects of low luminosity, however, lying at distances of a few million parsecs or more, would be completely lost among the galaxies of the distant background, so that the question is not very easy to settle in this case. On the other hand, galaxies with low surface luminosities are one class of low-luminosity objects about which something is known. It has been found by Rijves that the distribution of objects with low surface luminosities in the Virgo cluster is roughly the same as the distribution of high-luminosity galaxies. On the other hand, it cannot yet be established with any certainty whether galaxies at the low limit of surface luminosity (such as the Sculptor system or the Zwicky object in Capricornus) constitute a general metagalactic field or whether they are concentrated in clusters and groups.

c) The supergalaxies discussed above are objects with diameters of the order of 20 million parsecs. If these represent the largest inhomogeneities in the distribution of galaxies, then any given portion of space measuring 50 or 100 million parsecs across can be expected to have approximately

* Nonuniformity of the distribution of galaxies in the sky, aside from that caused by absorption in our Galaxy, was clearly attested to by the galaxy catalog of Shapley and Ames (stellar magnitude limit of 13.0). This nonuniformity is mainly due to the existence of the local Supergalaxy. An even more pronounced nonuniformity is revealed by the calculations of Shane and Wirtanen (stellar magnitude limit of 18.4). In this case, small-scale inhomogeneities are produced by the concentration of galaxies in clusters. There are also larger-scale inhomogeneities, which are a result of the tendency of clusters to form into groups similar to supergalaxies.

According to the data of Zwicky and others, the nonuniformities in the distribution of galaxies extend up to the limit attained by the Schmidt telescope at Palomar (nearly up to the 20th stellar magnitude). As an example, we cite the large galactic clouds in the vicinity of the Corona Borealis cluster. However, with respect to the tendency of clusters to crowd together, it is of interest to study the distribution of centers of galactic clusters. Such a study was carried out by Abell on the basis of the photographs in the Palomar Atlas. His findings prove that the distribution of clusters is nonuniform.

Zwicky suggests that the nonuniformities observed in the cluster distribution are mainly due to patchy absorption of the intergalactic dust. The arguments he adduces to show that intergalactic absorption occurs in well-defined directions are quite compelling, but there are still many cases in which the inhomogeneities cannot be explained in this way. Consequently, we must assume that galaxies at great distances from us actually have a nonuniform distribution.

the same amount of matter (galaxies) in it. It is possible, however, that inhomogeneities of a larger scale exist. Whether this is true or not can be decided only by studying the distribution of faint galactic clusters (up to the 21st stellar magnitude), or by studying the distribution of extra-galactic radio sources. The solution of this problem is very important, since it will provide a check of the various cosmological theories proposed. At present it can only be stated that no justification for the postulate of homogeneity usually adopted by cosmologists has yet been found.

d) It was mentioned previously that there is strong evidence for the existence of intergalactic dust matter. In this connection, a study of all the various kinds of intergalactic matter would be advisable. So far, the following kinds have been identified:

1) Luminous intergalactic matter, which sometimes fills the central part of the volume occupied by a galactic cluster. All the data indicate that this luminous matter consists of stars, in the same way as the bridges and bars often observed in binary galaxies do.

2) Intergalactic globular clusters, a few of which have been detected at distances of more than 100,000 parsecs.

3) Giant clouds of relativistic electrons which have been ejected from the interiors of galaxies. Radio source Centaurus A, for instance, consists of three such clouds, while radio source Cygnus A consists of two. Each cloud of this type is larger than a normal-sized galaxy, and many such clouds must have been scattered throughout intergalactic space in the past.

4) Absorbing dust. There do not seem to be any data available on the sizes of individual dust clouds.

5) Neutral gas masses, which seem to be present in such small amounts that the radiation they emit (for instance, in the $\lambda = 21$ cm line) has not yet been detected with any certainty.

Each of the foregoing kinds of intergalactic matter definitely deserves a special study.

II. BASIC FACTS RELATED TO THE KINEMATICS AND DYNAMICS OF GALACTIC SYSTEMS

Our knowledge of galactic motions is confined to information on the radial velocities of about a thousand galaxies. We have no data at all concerning their tangential velocities. Nevertheless, the available data on the radial velocities (nearly all of which were obtained at the Mount Wilson, Palomar, and Lick Observatories) have posed some of the most difficult problems which astronomy has ever had to face.

The totality of observable galaxies constitutes a part of some vast system which we call the Metagalaxy. The concept of the Metagalaxy, by the way, is meaningful regardless of whether galaxies exist beyond this system or not. The most important consequence of our information on the radial velocities of the galaxies is the fact that the Metagalaxy is expanding.

Hubble's law, which was derived from empirical data, states that

$$v_r = H \cdot r,$$

where v_r is the radial velocity of the galaxy, H is a constant, and r is the distance to the galaxy. This law, which is valid within minor fluctuations for values of r up to almost 2 billion parsecs, indicates that the observed expansion is approximately uniform. All attempts to find an explanation for the red shift other than the Doppler effect have turned out to be artificial and futile. Consequently, whenever we consider any problems concerning the nature, and particularly the evolution, of the Metagalaxy, we have to take into account its expansion.

Clearly, Hubble's law is valid only as an average. In addition to the velocity defined by Hubble's formula, each galactic cluster has its own peculiar velocity, as does each galaxy with respect to the center of gravity of its cluster.

For instance, in the Local Group, where the distances between galaxies are small, the relative velocities are mainly determined by the peculiar motions of the individual members. However, even the nearest galactic clusters and the nearest outer groups are receding from us, indicating that the peculiar velocities of these clusters and groups are small compared with the systematic recession velocities given by Hubble's law.

It is important to know the value of the constant H, since this makes it possible to determine the distances of the remotest clusters. Unfortunately, this value is not precisely known, although probably it lies somewhere between the following limits:

$$60 \frac{\text{km/sec}}{\text{megaparsec}} < H < 140 \frac{\text{km/sec}}{\text{megaparsec}},$$

and it is a fair guess that it lies between the narrower limits:

$$70 \frac{\text{km/sec}}{\text{megaparsec}} < H < 100 \frac{\text{km/sec}}{\text{megaparsec}},$$

according to the measurements of Sandage (1958). It will not be advisable to consider here the problems involved in determining H, but we should note that under any given conditions Hubble's law provides a good estimate of the relative distances.

Another important factor with respect to galactic motions is the existence of a certain dispersion of velocities within each galactic cluster, this being associated with internal motions in the clusters.

If a cluster is in a steady state, or if it is supposed to reach a steady state after a certain length of time, its total energy E must be negative:

$$E = T + U < 0,$$

where T and U are the kinetic and potential energies of the system. If $E > 0$, on the other hand, the system cannot reach a steady state, and at least some of its members must move off to infinity.

Recent investigations have shown that there are some groups and multiple systems for which the kinetic energy of internal motion (determined from the radial velocities) is many times higher than the probable

absolute magnitude of the potential energy; the latter was calculated assuming that the main mass of the cluster is concentrated in its galaxies and that the mass-luminosity ration $f=\frac{M}{L}$ for a given type of galaxy is of the same order as in cases when this ratio could be determined by studying the galactic rotation. This gave rise to the conclusion that some groups and clusters have a positive energy and should immediately become scattered throughout space. Such a conclusion was reached, for instance, for the galactic clusters in Virgo and Hercules, and also for the relatively nearby group in Sculptor. The latter case, which was analyzed in detail by de Vaucouleurs, is a particularly striking example, because its kinetic energy apparently exceeds the calculated absolute potential energy by one and one half or two orders of magnitude. Since a positive energy must cause some members of the cluster to wander away, and sometimes even makes the whole cluster disperse, it could be assumed that there is something in common between unsteady-state processes in clusters, on the one hand, and the expansion of the Metagalaxy on the other.

Systems such as the local Supergalaxy should occupy an intermediate position in this respect. The constituent parts of the Supergalaxy are receding from each other (for instance, the Virgo cluster and the group associated with M81 are receding from the Local Group of galaxies).

What we have said about the sign of the total internal energy of galactic clusters applies to multiple systems of galaxies as well. Apparently, some multiple systems have a positive total energy, indicating that their components must be rather young (of the order of 10^9 years old).

However, regardless of the sign of the total energy, another feature of the aggregate of multiple galaxies (triple, quadruple, etc.) is significant. Most multiple stars are known to have configurations of the "ordinary" type, whereas configurations of the "Trapezium of Orion" type occur in only a small percentage of cases ($\sim 10\%$). Approximately half of the multiple galaxies, on the other hand, have configurations of the Trapezium type. Inasmuch as systems of the Trapezium type are usually unstable, the time which has elapsed since these multiple groups were formed cannot be much longer than several periods of revolution of such a multiple system (one period lasts for 10^9 to $5 \cdot 10^9$ years).

Finally, since the assumption that all binary galaxies have a negative total energy occasionally yields improbably high values for the mass of the components, it is likely that some binary galaxies have positive total energies.

For superclose systems such as the radio galaxies, considerable differences in the velocities of the components are observed. In radio galaxy Perseus A, for instance, this difference is as high as 3000 km/sec. Consequently, such galactic pairs also have positive energies. In our opinion, what is observed in this case is the formation of a galaxy pair from a single galaxy.

When further data are compiled on the radial velocities of galaxies, it will be possible to answer many of the remaining questions concerning their kinematics and dynamics. Some of the problems still awaiting solution are the following:

a) More precise determination of the constant in the red-shift law. For this, the scale of extragalactic distances must be specified more accurately.

b) Determination of the red shift as a function of distance for very great distances. Departure from the linear dependence should undoubtedly be observed. A knowledge of the sign of this nonlinearity, and a determination of whether its value is independent of direction, is very important for the solution of fundamental cosmological problems.

c) It is very important to determine the peculiar velocities of the centers of gravity of individual galactic clusters (that is, the discrepancies between their observed velocities and Hubble's law). Solution of this problem is essential in order to determine whether there is a genetic relation between neighboring clusters. However, in order to determine these discrepancies, some way must be found to measure the distances of distant clusters more accurately, without using Hubble's law.

d) The solution of many problems concerning the dynamics of galactic clusters and multiple galaxies requires the determination of their masses. Unfortunately, if the galaxies in these systems are far away, their masses are determined statistically, proceeding from the assumption that the energy is negative and that the virial theorem is applicable. However, the masses of galaxies, even if only of the galaxies contained in the nearest clusters, must be calculated independently of this. In addition, methods must be found for estimating at least the upper limit of the intergalactic masses possible in each system (cluster or group).

e) Marked disagreements have sometimes been found between the mass of a system determined according to the virial theorem and the mass calculated according to the luminosities of individual members of the system. This has been observed for several diffuse clusters and galactic groups (the clusters in Virgo and Hercules, the galactic groups in Sculptor and Leo, etc.). Moreover, according to Zwicky, the large globular clusters do not show any signs of expansion. Recently, however, Agekyan came to the opposite conclusion concerning the globular cluster in Coma Berenices.

In order to settle this question finally, as many radial velocities as possible in several of the nearest large globular clusters will have to be determined.

III. BASIC FACTS RELATED TO THE NATURE OF GALAXIES AND GALACTIC CLUSTERS

Observations show that the known galaxies have a great variety of shapes and intrinsic properties. In order to gain a better understanding of the nature of galaxies, it is very important to have a fairly complete and yet simple system of classification of galaxies. It is quite obvious that the greater the physical significance of the classification criteria, the more useful the classification will be for solving problems in extragalactic astronomy.

The currently prevalent classification (that of Hubble) is based on a study of the external shapes of galaxies. It has proved to be extremely useful, since until recently all the information we have had on most galaxies was data on their shapes, integral brightnesses, and apparent diameters. The last two parameters cannot be used to characterize a

system unless the distance is also known. In recent years, however, it has become possible to find the approximate absolute brightness in terms of the linear diameter for a large number of galaxies contained in thickly populated clusters. This could be done because it was found that the brightest members of these clusters are always supergiants, with absolute magnitudes of the order of -21.0. By comparing this absolute magnitude with the apparent magnitude of the brightest members, it is possible to obtain a rough estimate of the distance, and thus of the luminosities and absolute dimensions of the other members as well. As mentioned at the beginning of the article, the luminosities of galaxies in clusters vary over a wide range. It has gradually become clear that denoting a given galaxy as a supergiant, a giant, an object of medium luminosity, a dwarf, or an object of extremely low luminosity (such as Zwicky's object in Capricornus) is quite often much more important than specifying its shape. Let us recall once more that a supergiant galaxy contains tens of millions of times more stars than a galaxy of extremely low luminosity does.

In order to understand the properties of a galaxy it is important to study its central region, and in particular to determine whether it contains a small central nucleus. Any new attempts to work out a classification of galaxies should take into account the luminosity; moreover, a specification of the galaxy class should also define the role of the central regions and possibly of the nucleus itself. Lastly, other, as yet unknown, parameters may exist which are very important for describing the state of a galaxy.

The recently proposed Morgan classification, which takes into account the degree of concentration of the luminosity, fulfills one of these requirements to a certain extent. Specifying the Morgan class, however, leaves the luminosity undefined. Lately an attempt has been made by van den Bergh to introduce a parameter derived from the observed shape of a galaxy, but essentially defining its luminosity as well. The basic idea here is quite good, but unfortunately the van den Bergh classification is not comprehensive and it covers only spirals of the more recent types. Therefore, it is likely that in the future new classifications will be proposed which will specify the essential parameters of every galaxy.

A significant advance was made during the second quarter of this century, with the introduction of the concept of galactic subsystems (Lindblad, Kukarkin, Baade) and the specification of different types of stellar populations. In some galaxies (EO systems) the stellar populations are fairly uniform, so that the whole galaxy may be said to comprise a single subsystem. This is true, specifically, of such members of the Local Group as the system in Sculptor, and of galaxies M32 and NGC147. Contrary to the opinion once expressed by Baade, we apparently do not encounter in nature systems consisting entirely of Population I stars (the type of stars in the spiral arms). In many galaxies, however, there is a superposition of two or several subsystems containing different types of populations.

For example, a lens-shaped galaxy (SO) consists of two subsystems, made up respectively of the stellar populations of a spherical component and a disk. Giant spirals of the M31 type consist of a spherical component, a disk, and spiral arms. It may be that a more detailed subdivision is required in these cases, but the main point is that here we have to do with the superposition of different subsystems.

The available data indicate that the populations of different subsystems follow distinct, independent lines of evolution. Moreover, there is also reason to believe that the average stellar age differs for different subsystems. Accordingly, if we disregard the dynamic interaction, each subsystem has an autonomous existence. This is an important factor when describing galaxies as composite systems apparently produced by a simple superposition of subsystems.

The relative independence of the different subsystems constituting a single galaxy is shown by the fact that the degree of development of one subsystem (in terms of its population density and size) is unrelated to that of the other subsystems.

For instance, the population density and dimensions of the spherical subsystem of galaxy M31 do not differ greatly from those of a normal EO galaxy, which has an absolute magnitude of about -19.0. The latter type of galaxy, however, contains no stellar population in a plane subsystem or spiral arms, whereas M31 has thick spiral arms and a densely populated disk.

In this respect it is also interesting to consider systems occupying an intermediate position (that is, systems in which one subsystem is highly developed and another is only poorly developed). A notable instance of this is galaxy NGC5128 (radio source Centaurus A), which appears to be a giant elliptical galaxy on overexposed photographs, but which actually contains in its central region a poorly developed plane subsystem containing a large amount of absorbing material. Studies conducted by the Burbidges, based on measurements of the radial velocities in this plane subsystem, have shown that the equatorial plane of the latter is approximately perpendicular to the equatorial plane of the elliptical subsystem. This is a good illustration of the independence of subsystems. Another interesting instance is NGC5718. The spiral arms of this galaxy are rather thin, but unlike those of NGC5128 they extend far beyond the volume occupied by the spherical subsystem. Dark matter is concentrated in a plane tilted about 25° to the equatorial plane of the elliptical subsystem of the galaxy, which is also an indication that the subsystems are independent.

It is possible to cite opposite examples as well, in which the spherical subsystem is very poorly developed and the plane subsystem is quite prominent. The Large Magellanic Cloud is an example of such a case. That this cloud contains a spherical subsystem follows only from the fact that there are in it at least about 30 globular clusters similar to those in our Galaxy and in M31. Unfortunately, however, other objects associated with spherical subsystems are very difficult to distinguish against the background of the stellar population of the plane component. It is therefore difficult to ascertain which elliptical systems the spherical component of the Large Magellanic Cloud resembles. Judging by the distribution and number of globular clusters in this component, however, it should be an elliptical galaxy of medium luminosity (16th absolute stellar magnitude) with a low density gradient from center to edge. As we progress down the scale from supergiant elliptical galaxies to elliptical galaxies of medium and low luminosity, we encounter objects with low density gradients more and more frequently.

Mention was made above of the comparative independence of the different subsystems included in a given galaxy. In one respect, however, the

subsystems are almost always quite definitely interrelated, in that they have a common center. The center of the spherical subsystem usually coincides with the center of the disk, and also with the region from which the spiral arms emerge. Observations of nearby high-luminosity galaxies indicate that this center is usually the site of a galactic nucleus, measuring only a few parsecs across (less than the diameter of an ordinary globular cluster). It is reasonable to assume that the origin of the separate nearly independent subsystems is in some way related to the presence of this nucleus.

In some galaxies, on the other hand, no traces of a nucleus have been found (for instance, in NGC185 and in the system in Sculptor). However, let us consider the absolute magnitudes of galactic nuclei. The absolute photographic stellar magnitude of the nucleus of M31 is -11.6, that of M32 is -11.1, that of M33 is -10.3, and that of NGC147 is -5.0. Consequently, we see that the absolute magnitude of the nucleus diminishes as the density gradient decreases. Therefore, the nuclei of NGC185 and the system in Sculptor, and possibly the nuclei of the Magellanic Clouds as well, should have luminosities which are even lower than the nucleus of NGC147. If this luminosity is of the order of -2, the nucleus may well become lost among the stars. It should be noted, moreover, that the nuclei in the Magellanic Clouds will be imperceptible even if their absolute photographic stellar magnitudes are as high as -5. It is thus a bit premature to conclude definitely that there are no nuclei in these systems. If they do have nuclei, however, they must be very faint.

It was mentioned above that the subsystems in virtually every galaxy are concentric. Some individual cases exist, however, in which this is not true; for example, in galaxy NGC4438 in the Virgo cluster, the two subsystems are clearly displaced with respect to each other.

There is a certain similarity between galaxies and galactic clusters: just as the stellar populations of galaxies can be roughly divided into two basic types, the members of galactic clusters can also be referred to two different types of population. The first type is associated with spiral and irregular galaxies, and the second with elliptical and lens-shaped (SO) galaxies.

Densely populated globular galactic clusters such as the cluster in Coma Berenices contain mainly Population II galaxies. Diffuse galactic clouds, such as the nearby cloud in Ursa Major, contain almost no elliptical galaxies of high luminosity. The nearby galactic group in Sculptor, which was studied by de Vaucouleurs, contains neither elliptical galaxies nor galaxies of types SO, Sa, and Sb. This group includes only spirals of later subclasses. The diffuse cluster in Virgo, on the other hand, contains both giant elliptical galaxies and giant spirals.

Let us consider whether in this case a superposition of different subsystems in one cluster is involved. There are not always indications that two quasi-independent subclusters have combined to form one system, although in some cases there is definite evidence of this. For example, in the Coma Berenices cluster one of the central galaxies (NGC4874), a supergiant of type SO, is distinctly surrounded by a symmetric cloud of elliptical galaxies of lower luminosity. Externally, this group bears a great resemblance to galaxy NGC4486, which is surrounded by globular clusters (the only difference being that, instead of globular clusters,

NGC4874 has elliptical galaxies of medium luminosity around it). The group of elliptical galaxies with NGC4874 at its center, however, appears to be superimposed onto a large and densely populated galactic cluster with a lower density gradient.

For diffuse galactic clusters it is apparently possible to find many more phenomena indicating that different groups are superimposed. A good case in point is the chain of bright galaxies M84, M86, NGC4435, 4438, etc., in the Virgo cluster. As Markaryan pointed out some years ago, this chain is not an accidental formation, but rather is an independent group which is superimposed onto the Virgo cluster.

It is quite possible that diffuse galactic clusters are in general produced by the combination and superposition of a number of similar groups (this would also explain their irregular shapes). In this connection it should be recalled that there are some clusters (or groups) which consist of a central galaxy surrounded by a certain number of objects of lower luminosity (for instance, the group around M101 forms such a system). This point is important because in such cases it appears certain that the central galaxy and its fainter companions have a common origin. It must be noted, however, that in addition to these systems there are also some groups which consist almost exclusively of supergiants (Stefan's quintet is an example of this). In contrast to the previous case, however, no appreciable number of low-luminosity galaxies is observed around these supergiants. With respect to this, however, we should note that the luminosity function may have a discontinuity and that this system may contain a number of galaxies whose absolute magnitudes are less than the lowest observable magnitude. The facts just considered, together with what we said at the beginning of the article concerning the special position of M31 and our Galaxy in the Local Group, indicate that the supergiant galaxies in clusters and groups are of considerable cosmogonic significance.

From the foregoing it is also clear that, in addition to investigating densely populated galactic clusters, it is very important to obtain as many data as possible on groups with relatively low populations. In particular, it is essential to ascertain whether any isolated groups exist which consist exclusively of low-luminosity galaxies. If there were no such groups, then this would imply that the cosmogonic processes occurring in high-luminosity galaxies play a decisive role in the formation of dwarf galaxies.

Although a certain amount of progress has been made in studying the stellar populations of galaxies and of the different subsystems, it must be admitted that only the first steps have been taken so far. Additional information on the composition of stellar populations must be obtained, on the basis of spectral data (as suggested by Morgan and Mayall), and on the basis of a quantitative analysis of spectrophotometric curves (Markaryan et al.).

Another important task lying before us is an analysis of the nature of the galactic arms. It has been observed that arms with the same degree of opening and the same length may, in different instances, have very different abundances in their stellar associations. If the nature of the galactic arms can be correlated with the other parameters of the galaxy, the factors causing these differences will be understood better.

The barred spirals (or SB galaxies) are particularly interesting. Unfortunately, however, we do not yet know exactly how the populations of the bars differ from the populations of the arms in these galaxies. We know only that the bars are usually much redder in color than the arms, and that the arms must thus contain a relatively larger number of young stars. It will be especially important to determine how many open clusters and supergiant stars the bars contain.

IV. AN EXTENSION OF THE SUPERPOSITION CONCEPT

In the foregoing we discussed some cases in which the centers of the subsystems composing a given galaxy are displaced with respect to one another. Some galaxies are also known which are binary but which are at the same time connected by a material medium, so that they can also be considered as single systems. Examples of such galaxies are M51, NGC7752, and NGC7753. It is reasonable to assume that these are galaxies in which the centers of the subsystems have separated. In the IC1613 system there is a superassociation lying to one side of the main galactic body, and this can equally well be considered either a part of the main galaxy or else a separate companion galaxy. It is quite probable that this superassociation, which consists of hot giants, was formed much later than the rest of the galaxy.*

Consequently, the impression is created that a galaxy evolves by means of the successive formation of different subsystems; any of the subsystems, or sometimes a group of subsystems with a new center, may become a companion of the main galaxy. This implies that the formation of a companion and the appearance of a new subsystem within a given galaxy are related phenomena.

It can be assumed, moreover, that these phenomena take place concurrently. For example, in cases where a spiral arm joins the center of a given galaxy to a companion, it seems reasonable that the spiral arm and the companion were formed together.

Finally, any companion revolving around a primary galaxy (such as the system in Sculptor) is very similar in size and stellar population to a globular cluster. Since globular clusters are most probably produced by internal processes occurring in the main galaxy, the same can be assumed to hold true for companions like the one in Sculptor.

V. TRANSIENT PHENOMENA IN GALAXIES

Up to this point we have considered galaxies as static formations. However, transient phenomena also occur in galaxies, especially in the supergiants, and these phenomena are of great interest.

* The same situation exists in IC2574: a bright superassociation lies to the north of the main part of this galaxy, the two parts being connected by a barely visible arm.

We are not referring here to the processes of stellar formation which take place in O and T associations, although these play a significant role in galactic evolution. What we have in mind are more rapid changes which are directly observable. It is noteworthy that most of these transient phenomena are associated with galactic nuclei and that they may even be regarded as manifestations of activity of the nuclei.

A) A stream of neutral hydrogen is flowing out of the central region of our Galaxy. This phenomenon was discovered by Dutch astronomers as a result of observations of the 21-cm radio-emission line of hydrogen. The same sort of gas-efflux process was detected for the nucleus of M31 by Münch, as a result of studies of the $\lambda = 3727$ Å line. In both cases the mass of the efflux amounts to about 1 solar mass per year. Oddly enough, this figure does not agree with existing estimates of the masses of galactic nuclei (about 10^7 solar masses).

B) Seyfert has demonstrated that for some galaxies with high-luminosity nuclei the $\lambda = 3727$ Å emission line is broadened considerably, which corresponds to velocities of motion of the order of several thousand kilometers per second. Such velocities exceed the usual escape velocities of galaxies. This undoubtedly indicates that intense fluxes of matter are ejected from the nuclei at high velocities and then dispersed throughout space. The amount of ejected matter in this case is apparently much greater than that released in our Galaxy and in M31. Presumably, the blue galaxies in Ara, which have strong emission lines in the regions near the nuclei, are of a similar nature.

C) The $\lambda = 3727$ Å line is also observed at the very center of radio galaxy NGC4486, and it is apparently associated with a quite intensive gas efflux at a velocity of about 500 km/sec. If this is correlated with the fact that a radial jet issues from the center of the galaxy and contains condensations which are strongly emitting in the radio range, we can conclude that the condensations were expelled from the central nucleus of the galaxy at high velocities. The light of these condensations is polarized, indicating that they contain high-energy electrons. These formations, however, are not on the same scale as the Crab Nebula, since the energy of their radio emission (measured in absolute units) is about ten million times higher. If we take into account that in this case the radio emission lasts at least a thousand times longer as well, then it follows that the energy reserves in these condensations are a billion times greater than the total energy reserves of the Crab Nebula. This means that, in terms of energy and mass, these condensations are objects which correspond to small galaxies, and this is found to agree with their absolute photographic magnitudes.

It is not yet known whether these condensations are ejected from the galactic nucleus as already-formed clouds of relativistic electrons, or (which is more probable) whether the nucleus expels objects which in turn continually produce new streams of such electrons. What is important, however, is that the nucleus of a giant galaxy is able to eject such immense condensations, a fact which does not seem to agree with the information we have on the masses of galactic nuclei.

D) It is much more difficult to explain the phenomena occurring in other radio galaxies. It is known, though, that galaxy NGC1275 (Perseus A)

is one of the Seyfert galaxies, in which the $\lambda = 3727$ Å line is broadened considerably for the central region. Thus, in this case also matter is ejected from the nucleus at a high rate.

The presence of two nuclei in radio galaxy Cygnus A may be the result of a recent splitting of one parent nucleus. According to our previous considerations, such a division should lead to the formation of subsystems with different centers and subsequently to the formation of a binary galaxy.

At any rate, the case of NGC5128 (Centaurus A) also shows that galactic nuclei are capable of ejecting either tremendous clouds of relativistic electrons or else material which can subsequently produce such clouds.

In any case, then, radio galaxies are systems in which the central nuclei show signs of intense activity ultimately leading to the formation of new condensations, new subsystems, and possibly even new galaxies. We may therefore safely say that in these cases the nuclei are cosmogonically active, although we still do not know where the masses involved in this activity come from.

E) There are some giant galaxies which have streamers coming out of their central regions. These streamers contain blue galaxies with absolute magnitudes of about -15 (that is, with luminosities higher than that of the condensation in NGC4486). Typical examples of such galaxies are NGC3561 and IC1182. The ejection of such condensations is another type of cosmogonic activity in galactic nuclei.

F) The fact that the spiral arms originate from the galactic nuclei themselves suggests that the generation of the arms is also directly associated with the nucleus.

G) Radio observations of the center of our Galaxy, carried out by Pariiskii and others, indicate that the state of the nucleus, which presumably consists mostly of new stars, differs markedly from the states of other aggregates of such stars (for instance, the globular clusters). The galactic nucleus itself is a source of thermal radio emission, while the surrounding region (with a diameter of about 500 parsecs) is a region of strong nonthermal radiation. These facts imply that the physical states of galactic nuclei differ greatly from the states of ordinary stellar groupings.

The quantitative evaluation of the ejected mass is one of the most important unsolved problems related to ejections and the efflux of matter from galactic nuclei. This applies equally well to galaxies whose central regions produce emission lines, and to radio galaxies and other cases involving discrete ejections. Even the meager information now available indicates that the findings may prove to be incompatible with the law of conservation of energy (and mass) in its present form, so that a generalization of this law may be necessary.

CONCLUSION

We have seen that the most important processes taking place in large galaxies are determined by the activity of the galactic nuclei. This activity can take various forms, and these were discussed above. There are two types of nuclear activity which are especially interesting; one of these is

related to the formation of spiral arms and the other is related to the formation of the stars and star clusters of the spherical component [Population II stars]. These processes apparently occur during different evolutionary stages and are accompanied by corresponding changes in the nuclei. It should be noted too that the different types of subsystems must be produced by different kinds of processes. For example, galaxy M32 apparently does not contain any globular clusters, whereas the other companion of the Andromeda Nebula (NGC205) contains at least nine of them. The most surprising thing with respect to this is that globular clusters are present in galaxies with very low density gradients.

If we adopt the hypothesis that galaxies are formed from diffuse star clouds, it is reasonable to assume that dense formations like globular clusters will appear in systems containing regions of very high density (and a high density gradient). Of course, such qualitative considerations cannot be considered satisfactory. The significant thing, however, is that the number of globular clusters per unit luminosity of Population II stars varies from system to system.

We thus obtain an additional parameter for the description of spherical systems and subsystems. The relationship between this parameter and the other parameters of these systems (total luminosity and density gradient) must be determined by observation.

Statistical data pertaining to multiple galaxies and galactic clusters show that these systems could not have been formed by the mutual capture of initially independent galaxies. The components of these systems must therefore have a common origin. This point was considered in detail in our report at the Solvay Conference in 1958.

The above-mentioned data on the ejection from galactic nuclei of condensed masses which turn into complete galaxies of medium or low luminosity, and also the data on the division of galactic nuclei, indicate that multiple systems and whole groups are probably created as a result of the division of a single parent nucleus into several nuclei. This division may take place in successive stages.

In cases when a group contains a central galaxy with a high luminosity, the formation of faint galaxies must be connected primarily with activity of the nucleus of the high-luminosity galaxy.

The nuclei of giant and supergiant galaxies have very high activities, as indicated by the fact that radio galaxies are usually among the brightest members of the clusters of which they form a part. If one of the galaxies in such a cluster is clearly predominant, this usually turns out to be the radio galaxy itself.

Observations show that although all the large clusters contain supergiant galaxies, only a small number of these are radio galaxies. Radio-emissive activity must accordingly constitute a relatively brief phase in the evolutionary history of a galaxy. The liberation of radio-emissive agents is presumably a phenomenon associated with the ejection of very large masses from the galactic nuclei, and it probably occurs only at a certain stage of a given cosmogonic process.

Even though extragalactic astronomy has at its disposal considerable means for studying the activity of galactic nuclei, the information we have on the various forms of this activity is still extremely meager. We know even less about the parameters characterizing the integral properties of the nuclei (luminosity, mass, color, size, and rotation). Finally, we

know nothing about the internal structure of galactic nuclei. Consequently, this particular aspect of extragalactic astronomy deserves extensive study. Let us now list some of the tasks involved in such a study.

1. Determination of whether all galaxies have nuclei. If some do not, then the characteristics of these must also be determined.

2. Determination of the integral characteristics of the nuclei for as many galaxies as possible. With respect to this, the difficulty involved in studying galaxies with high density gradients must be taken into account. It should be noted, though, that many galaxies of type Sc have nuclei which are so distinct that they can be studied without much interference from the central condensation around the nucleus.

3. Determination of the relationship between the integral parameters of galactic nuclei and the parameters of galaxies.

4. The study of the spectra of nuclei, in order to detect emission lines, rotation, and the ejection of matter.

5. The study of the relation between the nucleus and the bar in a barred galaxy, and also of the relation between the bar and the efflux of matter from the nucleus.

6. The study of galaxies with multiple nuclei, and of the radial velocities of the individual components of these nuclei.

7. Determination of the number of globular clusters as a function of the nature of the galactic nucleus.

In the foregoing we have presented some considerations of cosmogonical nature relating to the origin of galaxies. In all cases, it was attempted to remain within the domain of facts and not to make speculations. An analysis of the observations shows that the phenomena related to galactic origins are so unusual that it would have been impossible to predict them on the basis of any theoretical considerations. Thus, we are here confronted by a striking phenomenon which has recurred continually throughout the history of science. Whenever a new domain of phenomena is investigated, unsuspected relationships are discovered, which go beyond the framework of existing concepts. This, of course, makes each such domain of phenomena all the more interesting. Consequently, we must gather facts and make observations even more carefully, since more precise data on the actual objects and more extensive information on the structures of the various parts of galaxies, together with a thorough analysis of the findings, are the only means of solving the difficult problems related to this subject.

B.A. Vorontsov-Vel'yaminov

FACTS AND PUZZLES CONCERNING THE STRUCTURE OF GALAXIES

The views of V.A. Ambartsumyan on the origin of galaxies are often interpreted, especially in the west, as a hypothesis about the instability of multiple systems and galactic clusters. In point of fact, Ambartsumyan's ideas on this subject are much more comprehensive than any hypothesis concerning the mechanical instability of galactic groups. The main thesis of his theory is that galactic centers are superdense formations, which are highly active. Their splitting gives rise to multiple galaxies, while the ejection of smaller masses of superdense prestellar matter produces spiral arms, globular star clusters, and diffuse matter. We would like to dwell on some considerations related to Ambartsumyan's theory.

The interesting idea of checking statistically whether double galaxies originate simultaneously, specifically by the splitting of a single one, or whether they are produced as a result of capture was advanced by Page /1/. His preliminary findings led to some unexpected and implausible results, and it became clear that his apparently simple idea is in practice complicated by a number of factors which have to be studied.

It seems to us beyond doubt that physical double and multiple systems have a common origin. This has been well established by V.A. Ambartsumyan and others. In particular, interacting galactic pairs, which are evidently physically coupled, are so frequent that they could not possibly be produced by random encounters.

The capture theory has been thoroughly studied in connection with O.Yu. Shmidt's cosmogonic hypothesis. It was shown that for capture to take place a very unique approach of three bodies is required. The possibility of capture among the isolated galaxies of the field in which interacting galaxies are commonly encountered is therefore highly unlikely.

The velocity difference in physical pairs is also on the average lower than the peculiar velocity of the galaxies. This is an additional strong argument against the capture theory.

Less certainty prevails where the instability of clusters and groups and their positive energy are concerned. Most authors tend to draw conclusions about the instability of the small groups brought under study on the basis of the known radial velocities. The calculations, however, involve a number of supplementary assumptions and some inaccurate data. These include the distance to the group, and the assumption that the directions linking a few galaxies in pairs are randomly distributed, with uniform probability, etc. An analysis of the possible calculation errors, carried out by Limber and Matthews /2/, shows that the results are quite unreliable. It is interesting to note that there were even cases where the determination

of the radial velocities of components which seemed definitely to belong to the same group yielded values differing by hundreds and thousands of kilometers per second from the mean velocity of the group. It thus becomes doubtful that such galaxies actually belong to a group, in spite of their apparent size and position in the sky. If we want to consider them as members of a group, we must necessarily conclude that the group has been formed by an explosion. The fact that the configurations of these components do not display any visible perturbations cannot be construed as evidence that their projection in space is accidental, though; such perturbations are apparently not of gravitational origin and are sometimes absent at quite small distances, while in other cases they are observable at considerable distances between the components. Matters are further complicated when galactic clusters are considered, because it is even more difficult to single out the member of a cluster. The size of any cluster is always much less than the distance to it. Thus the members of a cluster cannot be differentiated from a background galaxy situated, say, five cluster radii away from it along the line of sight. This is borne out by the fact that, for instance, there are many investigators who no longer consider the cluster in Virgo as a single cluster.

In addition to this, it has been pointed out by Holmberg that the determination of the radial velocity possibly involves some systematic errors associated with the brightness of the galaxies.

In general, however, it seems most likely that at least part of the multiple galaxies are actually receding from each other.

Ambartsumyan considers that systems of the Trapezium type are young and unstable. The same view is held by the Burbidges /3/ with respect to the tight galactic chains discovered by B.A. Vorontsov-Vel'yaminov. But these groups also include some elliptical galaxies, which are considered very old formations. The author has already pointed out elsewhere /4/ that the presence of very long connecting filaments and tails indicates, however, that such galaxies have existed for a long time and are fairly stable. The elliptical galaxies included in chains and trapeziums may be subjected to the following considerations:

1. Such elliptical galaxies are young, although it is not yet known in what way they might differ from old elliptical galaxies.
2. These are not elliptical galaxies, but only appear to be so (this view has not yet been confirmed).
3. Notwithstanding mechanical considerations, the systems in which they are included may be old and stable. Might it not also be possible that in an old, initially stable system a mutual repulsion could subsequently develop, as a result of galactic evolution?

Many people are puzzled by the question of the origins of the literally fantastic energies which make the fragments of a divided galactic center scatter with velocities of hundreds of kilometers per second. The break-up of galactic centers may perhaps be attributed to the ordinary properties of superdense prestellar material, but then it becomes difficult to explain what causes the mutual recession of already formed galaxies which interpenetrate and have independent rotations.

If we base ourselves on the law of gravitation, the available data fail to allow for the enormous masses in the centers of some galaxies still consisting of superdense matter. The existence of such active centers in the younger galaxies should be detected by observation. Ambartsumyan

considers that the "surge" from the center of the NGC4486 galaxy is a sign of such activity. That this is indeed a "surge"—as it is commonly called—has not yet been proved. Galactic centers should be investigated more thoroughly, in order to find whether they show traces of activity.

Some new data seem to confirm, though perhaps not completely, Ambartsumyan's view that galactic centers have a special significance. Thus, for instance, the outflow of gas observed to take place from the nuclei of our Galaxy and other galaxies is hard to explain by ordinary processes. The unusually fast rotation of the centers which markedly differs from that of the surrounding regions, and the dark filaments issuing almost from the exact center of the M31 galaxy, are also indicative of the peculiar nature of galactic centers. This last might seem to prove Ambartsumyan's idea that spiral arms are formed by the ejection of relatively small superdense masses from the center. It is difficult to imagine though how spiral arms could be formed in this way. First of all, a fragment of superdense matter should move in a straight line after being ejected. Further, in order to form a spiral arm it should continuously release along its path matter which would turn into stars and gas. It is true that galaxies of the Sc type are observed, in which the spiral arms consist partly of widely spaced condensations, but such cases are generally rare among spiral galaxies. It is also difficult to explain the fact that spiral galaxies mostly have two arms, that the arms often branch out not from the center but from the ends of a bar, and that there are galaxies with a large number of branches issuing from the center in a single equatorial plane.

To all appearances, the spiral arms develop inside an already existing disk or from it, rather than disks being the result of the dispersion of spiral arms. The arms are usually completely disconnected from the center. They often begin at the periphery of the disk or within it. There are sometimes internal and external spirals, which are not connected with each other. They branch out from a ring, sometimes in pairs from a single point, or are completely isolated from the internal regions.

Ambartsumyan's assumption that during the formation of the various structural elements the galactic centers eject fragments in various planes may be to a certain extent substantiated by a number of specific examples. There occur structures in which the major axes are variously orientated in the same plane, as well as some systems, like M82, for instance, in which there are streams of matter directed perpendicular to the principal plane of symmetry.

We consider as more probable the hypothesis that the components of multiple galaxies originate jointly in close proximity and proceed to draw apart in the course of their formation. Some kind of repulsion sometimes grows up between them, causing their mutual recession in spite of gravitation. The material experiencing the strongest repulsion forms tails. The high viscosity of the stellar systems, which must be assumed, leads to the formation of bars. The stability of the tails and bars is the same as that of spiral arms, and is thus considerable. The nearness of a galaxy disturbs for some reason the development of a spiral structure and leads to its "becoming disfigured". The phenomena responsible for the repulsion of interacting galaxies must be related to the phenomena causing the mutual recession of galaxies in groups.

It should be recalled that while the Metagalaxy is made up of galaxies, it represents at the same time a unique type of continuous medium in which

the galaxies are condensations. Experimental physics has never had to deal with anything even remotely similar to it. Phenomena may therefore be discovered on a galactic scale which are utterly unexpected and as yet incomprehensible.

It is not impossible that paired galaxies should have properties quite different from those associated only with the attraction of their combined masses, similarly to the way in which the properties of molecules differ from the properties of their constituent atoms.

Certain pairs of living organisms are capable of reproduction, certain pairs of atoms exhibit new properties when combined, etc., and these properties cannot be deduced from a knowledge of the properties of the individual components. There may be something similar in the galactic world as well. This seems to be borne out by the fact that, according to Zwicky, galactic clusters apparently do not interact gravitationally with each other.

REFERENCES

1. PAGE, T.L.—Astron. J., 61. 1961.
2. LIMBER, D.N. and W.G. MATTHEWS.—Astron. J., 132, 286. 1960.
3. BURBIDGE, G.R. and E.M. BURBIDGE.—Astron. J., 131, 742. 1960.
4. VORONTSOV-VEL'YAMINOV, B.A.—A. Zh., 34, 8. 1957.

V.S. Brezhnev

NEW IDEAS IN COSMOLOGY AND ASTROPHYSICS

From 26 to 28 June 1961 a conference on extragalactic astronomy and cosmology was convened in Moscow under the auspices of the Cosmogony Commission of the Astronomical Council of the USSR Academy of Sciences. The conference was organized as a preparation for the symposium on these subjects which was to be held (in the USA) at the forthcoming Eleventh Congress of the International Astronomical Union in September 1961. Many prominent Soviet scientists participated in the conference and some very interesting reports were presented.

The main problems related to extragalactic research during recent years were considered in the comprehensive report of V. A. Ambartsumyan (Byurakan Astrophysical Observatory).

B. A. Vorontsov-Vel'yaminov (GAISh) concentrated in his report upon interacting galaxies and the physical interpretation of the observed galactic interactions.

The distances, motions, and distributions of galaxies within a sphere with a radius of 15 megaparsecs were discussed by Yu. P. Pskovskii (GAISh). He indicated that the complex of galaxies located within a sphere of radius 10 megaparsecs around our Galaxy is in a state of isotropic expansion associated with a rotation about some center lying in the constellation Virgo. A comparison of the distribution of galaxies and the nature of their motions makes it possible to specify the approximate pattern of galactic motions in our part of the Metagalaxy.

E. A. Dibai (GAISh) suggested that the asymmetric distribution of gas and dust in the spiral galaxies be interpreted as a result of the combined action of rotation and radial motion along the arms. A comparison between the results obtained from this analysis and the observational data indicates that the spirals become twisted during the evolution of the spiral galaxies.

The joint report of Ya. A. Smorodinskii and B. M. Pontecorvo (Joint Institute for Nuclear Research at Dubna) was received with great interest. This report dealt with the possible role of neutrinos in astrophysics and cosmology. The two authors presented strong arguments in favor of the existence of a considerable neutrino-antineutrino background in the universe. In the present epoch the energy of the background particles may be very low, as a result of an adiabatic reduction of the energy during the expansion of our part of the universe. During earlier evolutionary stages, however, the energy possessed by neutrinos may have been many orders of magnitude higher than the energy density of heavy matter. According to the available data, it is possible that even now the energy

density of neutrinos in the universe is comparable to that of nucleons, and that it is many times greater than the energy density of visible radiation. Consequently, neutrinos must play a significant part in determining the geometry of the world. During previous stages in the evolution of the universe, isotropically and uniformly distributed neutrinos may well have completely determined the space-time metric*.

D. A. Frank-Kamenetskii (Atomic Energy Institute of the USSR Academy of Sciences), in developing his theory of the spontaneous instability of a vacuum, considered the hypothesis of the multiple production of nucleon pairs. This hypothesis is a modern variant of Boltzmann's fluctuation hypothesis. The gist of Frank-Kamenetskii's hypothesis is as follows. The universe is assumed to be an infinite expanse which is essentially flat and free of matter. Somewhere in it, immense fluctuations of the vacuum take place very infrequently, accompanied by the formation of a colossal mass of neutrons and antineutrons. The presence of this mass causes a local twisting of space, which in turn leads to a local expansion of space. During this expansion, particles and antiparticles are annihilated and radiation is emitted. Turbulent motions arise, and eddies having unimaginably vast dimensions are formed. At a point in space where a neutron excess is accidentally created, a world similar to ours comes into existence (that is, a large accumulation of galaxies). In the event of an excess of antiparticles, on the other hand, an "antiworld" is created. The probability of such a fluctuation of the vacuum may turn out to be very low, but it will nevertheless not be zero.

The gravitational condensation of galaxies and globular clusters of stars was discussed by L. M. Ozernoi (GAISh). He considers the structural development of the Metagalaxy to be a consequence of the gravitational instability of a nonuniform, essentially gaseous, medium with a temperature of the order of 10^6 degrees centigrade and an average density of $5 \cdot 10^{-29}$ g/cm^3. Calculations show that in such a medium large condensations will form at first, and the cooling of these will make them susceptible to partition into individual protogalaxies. The latter will be stable with respect to disruptive tidal action. In addition, Ozernoi considered the formation of globular star clusters via a gravitational condensation of part of the protogalactic medium, which makes it possible to explain qualitatively certain observational data. In connection with this, he also concluded that the size of a globular cluster increases with the galactocentric distance, and this is in good qualitative agreement with observations.

G. I. Naan (Member of the Academy of Sciences of the Estonian SSR) reviewed certain philosophical works which excessively simplified or distorted the concept of cosmological infinity, and he pointed out how this concept should be considered from the viewpoint of modern physics.

The idea of an infinite cosmic expanse filled with a countless number of stars goes all the way back to the time of Democritus. This theory of an infinite universe first encountered difficulties in the middle of the 19th century, in connection with the so-called photometric paradox. The German astronomer Olbers demonstrated that if there were an infinite number of stars distributed uniformly throughout an infinite Euclidean universe, the sky would have to shine with a dazzling light, against the

* The metric here refers to the expression for the elementary interval between two infinitely close points of a space-time set.

background of which our Sun would show up as a dark spot. The situation would be analogous for a uniform distribution of galaxies throughout an infinite space. Then, at the end of the 19th century, the gravitational paradox was discovered. Seeliger, another German astronomer, showed that on the basis of Newton's theory of universal gravitation the total attraction which all the particles of an infinite universe exert upon each individual particle in the universe (including the Earth) would be infinitely great.

The existence of the photometric and gravitational paradoxes induced many scientists to construct geometric models of a finite unbounded universe which closes upon itself as a result of an inward curvature. Long ago, Riemann pointed out that it is possible for the world to be finite and at the same time unbounded. The surface of a sphere constitutes a two-dimensional analog of such a world. The area of a spherical surface is finite, but an imaginary two-dimensional being moving over such a surface would nowhere be able to detect the limits of his world, regardless of the length of the path it traverses. If this being maintained a constant direction of motion, then after some finite distance had been covered it would return to the starting point, having thereby completed a "round-the-world" journey. In other words, a spherical surface closes upon itself by virtue of its curvature.

From the point of view of relativistic cosmology, which is based on Einstein's theory of gravitation, a finite, unbounded universe closed in three dimensions is in principle quite permissible.

In his report Naan also stressed the fact that, whereas unboundedness in space and infinity in space amount to the same thing for Euclidean space, this is no longer the case when a more general, non-Euclidean geometry is used to describe the universe. He also gave the correct formulation of the problem by pointing out that at the present level of scientific development the most probable conclusion is the following: the universe has unbounded extension in space and time, and at the same time it is infinite in space and time. With respect to a purely spatial projection, the theoretical possibility exists that the universe is finite, but this possibility is not realized in practice. It is Naan's opinion that the problem of cosmological infinity should be solved by the combined efforts of astronomers, physicists, and philosophers.

On the basis of a study of cosmological solutions of Einstein's gravitation equations, E. M. Lifshits, I. M. Khalatnikov, and V. V. Sudakov (Institute for Physical Problems, USSR Academy of Sciences) demonstrated in their joint contribution that the existence of a physical singularity in time, at which the density of matter becomes infinite, is not a necessary consequence of cosmological models in the general theory of relativity.

In the general case of an arbitrary distribution of matter and a gravitational field, there is no physical singularity. The findings of Lifshits, Khalatnikov, and Sudakov rule out the possibility of the appearance of such a singularity in the future. This means that a contraction of our part of the universe (if it takes place) must inevitably turn into an expansion.

A. L. Zel'manov (GAISh) presented his theory of an anisotropic, nonuniform universe. He criticized the theory of a uniform, isotropic universe, and pointed out that the postulate of homogeneity involves an

unjustified extrapolation to the entire universe of the properties and characteristics of the observable portion of it. The formulation of a relativistic theory describing an anisotropic, nonuniform universe involves several other problems as well, and it leads to a reconsideration of the basic questions related to cosmology. One of the problems requiring such a re-evaluation is the problem of whether space and time are finite or infinite.

Zel'manov demonstrated mathematically that, when applied to the whole universe, the mutually exclusive, opposite concepts of "finite" and "infinite" no longer have the simple meanings which we are accustomed to give them on the basis of our experience of the macroscopic world. According to the anisotropic model of the universe, which takes into account the general theory of relativity, spatial finiteness or infinity is relative: with respect to single material frames of reference having a single motion, the universe is infinite, whereas with respect to other frames of reference it is finite. Thus it follows that our customary conceptions of "infinity" and "finiteness" are inapplicable to the universe as a whole.

It was also established by Zel'manov that in an anisotropic, nonuniform universe the spatial deformation may be so irregular that an expansion of the space in one region can be accompanied by contraction of the space in another region. Finally, he pointed out too that the anisotropy can affect the behavior of a volume of space so much that a regular volume minimum becomes possible instead of a singularity.

M.F. Shirokov (Moscow Aeronautical Institute) and I.Z. Fisher presented their theory of a nonuniform, isotropic universe. They noted that Fridman's theory of a universe which is evolving in time does not formulate the problem of cosmology correctly, and they offered a formulation which is physically and mathematically more correct. The solutions obtained by Shirokov and Fisher do not involve the difficulties, related to the infinite density of matter at some initial moment and to the finite lifetime of the universe, which plagued Fridman's theory.

Ya. A. Kipper (Institute of Physics and Astronomy, Academy of Sciences of the Estonian SSR) discussed the gravitational paradox in Newton's theory of gravitation, and he indicated a possible means of eliminating this paradox.

In a second contribution, A. L. Zel'manov also considered the gravitational paradox in the quasi-Newtonian approximation, and he analyzed the reasons for it.

I. D. Novikov (GAISh) discussed some cosmological models in the quasi-Newtonian approximation.

A number of other interesting reports were also presented at the conference. It is to be hoped that this conference on extragalactic astronomy and cosmology will have a stimulating effect on the future development of these two fields of study.

I. Ya. Ballakh

*THE ROLE OF EXPLOSIVE PHENOMENA IN COSMOGONIC PROCESSES**

In ancient times the science of the Earth was simply a description of the geometry of the flat surface of the planet. Now, however, the Earth sciences include a series of geological and geographical sciences which study the shape and size of the Earth, the regularities in the development of surface and underground processes, the formation of rocks and minerals, the distribution of rocks and minerals, and methods of prospecting for various rocks and mineral products. Boundary sciences like geophysics and geochemistry have now become independent sciences. Similarly, the science of the universe, astronomy, is being transformed from a purely descriptive science into a theoretical science, and (with the conquest of outer space) into an applied science as well.

So far, geology and astronomy have developed almost independently of one another, although some scientists (for example, Vernadskii and Lichkov /7/) have made studies of the relation between the two sciences. Recently, however, a rapprochement between geology and astronomy has been noted, and this was recognized in a resolution of the Central Committee of the Communist Party of the Soviet Union and the Council of Ministers of the USSR on 3 April 1961. The sciences of the Earth and the universe were discussed especially in this resolution. The Earth sciences were called upon to ascertain the regularities in the natural processes involving the world as a whole /19/. This interpretation of the role of these sciences creates conditions favorable for solution of the problems common to geology and astronomy; such problems come up both during research studies and during the solution of applied problems.

When studying the origin and development of the Earth as a planet, together with its development as an object of geological research, we are led to ask what factors modify the geological situation during different epochs. One of the reasons why we have written the present article is to try to ascertain the causes behind these modifying factors.

Let us start by considering some hypotheses concerning the origin of the solar system. We shall stress the aspects of these hypotheses which are not contradicted by geological, geophysical, and astrophysical research and which thus will be useful for working out a new theory.

Kant stated that in a rotating nebula "the central condensations form a Sun and the smaller masses become planets." Essentially this same theory was held by Faye and du Ligondes, and then, on the basis of his

* This article serves as a statement of the problem (Editors of Collection).

observations of nebulae, by Herschel as well /2, 11/. Subsequently, however, it was discovered that the spiral nebulae are incommensurably larger than the solar system. Shmidt /18/ suggested, and along with his successors developed, the hypothesis that the planets of the solar system were formed from a cold swarm of meteoritic dust which was captured by the Sun from outside. The gist of this theory (the formation of the planets from a cold swarm of dust) is now accepted by most scientists. However, the assumption that the Sun captured a dust swarm involves a number of theoretical difficulties. Consequently, V.A.Krat /2/ assumes that the Sun and the planets were formed out of a single interstellar cloud, and Fesenkov /16/ also adheres to the point of view that the Sun and planets were created simultaneously.

The above hypotheses do not consider the subsequent development of the solar system or the effect of this development on the evolution of individual planets (including the Earth); therefore, they do not take into account geological processes. Moreover, there are many facts which indicate that the physical conditions related to the Earth were different during different geological epochs. Some of these facts are: a) different sediment-accumulation conditions at different times /13/; b) tectonic movements of the Earth's crust /3/, causing deformations of the crust strata in geosynclinal regions and on platforms, the orientations of the directions of the deformation zones being different during different periods /17/; c) the presence of faults in the Earth's crust /9/ and mutual shifting of the rocks in the fault zones (thrusts, upthrusts, overthrusts, etc.); d) different orientations of the geophysical fields (for example, the geomagnetic field /6/) during different geological epochs; and e) continental drift (of the Wegener type), whose existence is now being demonstrated more and more convincingly.

The indicated geological processes can be explained by assuming that explosions occur on celestial bodies. Such an assumption also makes it possible to recognize a periodicity in the origin and evolution of the solar system.

The possibility of outbursts and explosions on stars and planets has been noted by a number of scientists. For example, with respect to stars, variations of the stellar spectral characteristics indicate single /20/ or repeated /1/ stellar outbursts or even whole series of such outbursts /4/. Transformations of stars into gaseous nebulae /1/ are also noted. Here we should mention that, according to the opinion of Fesenkov, the Sun can also undergo analogous transformations /2/, and Ambartsumyan believes that there is no pronounced difference between the evolutions of stellar and planetary systems /2/. The possibility of explosive processes on the Sun is indicated by Stanyukovich /14/ and by Pikel'ner /10/. With respect to planets, on the other hand, the origin of the asteroid belt lying between the orbits of Mars and Jupiter can be explained /12/ by assuming that the formerly existing planet Phaëthon disintegrated during a single explosion (Olbers, Fesenkov) or during a series of explosions (Putilin, Hirayama, Jung). This is an example of an explosion on a planet. The possibility of such processes on planets is also mentioned by Polak /11/ and by Vsekhsvyatskii /5/.

In this article, we shall not attempt to analyze in detail the nature and causes of the various explosions taking place on celestial bodies. It is

important to note, however, that abrupt changes take place during the evolution of these bodies, and during the evolution of nature as a whole as well, and that in the given case explosions caused by various processes constitute such changes, Here it should be kept in mind that explosions of this type are not random catastrophic phenomena in nature, but rather represent logical necessary steps in the evolution of the material world. Such discontinuous steps are expressions of the laws of the energetic redistribution of matter at certain stages in the evolution of the world. These processes may well be called universal, since they take place for such small objects as elementary particles and such large objects as gigantic celestial bodies or even systems of these.

Consequently, if we assume that the principle of the evolutionary development of nature with discontinuous steps applies to planetary evolution, then the origin and development of the entire solar system, and also the evolution of the Earth as an object of geological study, can be represented as follows.

In the remote past the Sun had a comparatively cold, heavy outer envelope, which originated as a result of the condensation of a cold interstellar cloud rotating about its own axis. Beneath the external envelope of this primordial cold Sun, the heating of matter took place. The high internal pressure and the rising temperature created conditions favorable for the initiation of a chain thermonuclear reaction involving the atoms of certain elements situated in the regions deep beneath the envelope. This resulted in an explosion, in which the shattered masses of the solar envelope were scattered in all directions. Some of the mass fragments from the envelope fell back onto the surface of the Sun, either immediately or else after several rotations about the Sun. Another part of the shattered mass, the particles of which had sufficiently high space velocities, formed into a swarm of meteoritic dust around the Sun. During the formation of the explosion-caused dust swarm, the dust particles became differentiated in space according to density. The particles from the shattered envelope which escaped from the Sun in the equatorial zone or near it possessed a maximum angular momentum, by virtue of the solar rotation (the central body thereby undergoing angular braking). These particles formed, in the region around the Sun, the basis for the swarm of meteoritic dust within which the planets of the solar system subsequently were to develop, in accordance with the cosmogonic theory of Shmidt /18/. Thus, it is our opinion that it is not necessary to assume that the Sun captured a swarm of meteoritic dust from outside.

The particles of the broken solar envelope may have been accelerated by more than one brief explosion. As nuclear reactions ignited the solar interior, explosions could recur periodically /14/, filling the space around the Sun with meteoritic dust. The initial explosion of the envelope of a celestial body may also occur under conditions when the energy of the nuclear reactions is insufficient to heat up the entire original star. In such a case, the creation of the meteoritic dust is not always accompanied by an ignition of the source (by the formation of a luminous star). Consequently, the swarms of meteoritic dust out of which larger celestial bodies will subsequently be formed may accompany cold, dark stars as well as ordinary stars. It is possible, too, that types of explosions of celestial bodies may take place in nature which result in the formation of dust swarms that do not have monolithic central parts. Then, just as in

the case of partial explosions of celestial bodies, the meteoritic dust may either be collected again into a single body, or may form several independent bodies, or it may supplement the masses of other celestial bodies and change their angular momenta.

Asymmetrical explosions on planets may, without leading to destruction of the planet, displace the planetary center of mass, as a result of which external-force moments will be produced. As time goes by, the celestial body works toward a reduction of the external-force moment and toward a stable situation. The reduction of the external-force moment must take place mainly via a redistribution of the mass of the body. For example, such a redistribution was effected on the Earth by means of the previously mentioned continental drift, and it is revealed, in particular, during studies of the paleomagnetism of the Earth /6/. Displacements of individual regions or continents continue as long as the shifting forces are available, that is, as long as the external-force moment of the body is not completely compensated. The nature of the tangential forces necessary to produce the tremendous thrusts and overthrusts taking place at various depths in the Earth's crust is explained convincingly and comparatively simply by the above scheme. These external-force moments, which modify the spatial orientations of the rotation axes of celestial bodies (in particular, the Earth) and which cause mass displacements, change the orientation of the Earth's surface relative to the Sun accordingly. Thus, there are particular zones in which the geological conditions are right for the formation of certain rocks and minerals /13/.

Following the above general scheme, we may remark that the formation of central bodies (the Sun) and peripheral bodies (the planets) simultaneously (Fesenkov) during a single condensation of an interstellar cloud (V.A.Krat) represents a definite phase in the evolution of a solar system. This evolutionary phase, which corresponds to the time interval between the accumulation of the cold cloud into a large body and the beginning of mass and momentum transfer from it, is a phase during which attractive forces compete with repulsive forces.

One of the reasons for writing this article was to illustrate the nature of the forces responsible for variations in the geological situation during different epochs. If the article proves to be of some use to the Earth sciences, then our studies of these forces have not been in vain.

If the described scheme can be extended to serve as an approximate description of the origin and development of other stellar-planetary systems, then we may conclude that the number of planets in the universe on which conditions are favorable (according to Oparin /8/) for organic life must be very large, and apparently is commensurable with the number of stars in the sky.

The author expresses his sincere thanks to N. I. Taranov and to K. M. Sadilenko for their discussions of the article, their valuable comments, and their advice.

REFERENCES

1. AMBARTSUMYAN, V.A., E. R. MUSTEL', A.B. SEVERNYI, and V.V. SOBOLEV. Teoreticheskaya astrofizika (Theoretical Astrophysics). — Moskva, Gostekhizdat. 1952.
2. BARABASHOV, N. P. Razvitie vzglyadov v oblasti kosmogonii Solnechnoi sistemy (The Development of Views on the Cosmogony of the Solar System). — Kharkov, Izdatel'stvo Khar'kovskogo universiteta A. M. Gor'kogo. 1953.
3. BELOUSOV, V. V. Osnovnye voprosy geotektoniki (Basic Problems in Geotectonics). — Moskva, Gosgeolizdat. 1954.
4. VORONTSOV-VEL'YAMINOV, B. A. Belo-golubaya posledovatel'nost' na diagramme Resselya; interpretatsiya belo-goluboi posledovatel'nosti na diagramme Resselya (The White-Blue Sequence on the Russell Diagram; Interpretation of the White-Blue Sequence on the Russel Diagram). — Astronomicheskii Zhurnal, Vol. 24, Nos. 2, 3. 1947.
5. VSEKHSVYATSKII, S. K. Konferentsia po voprosam proiskhozhdeniya i evolyutsii komet i drugikh malykh tel Solnechnoi sistemy (Moskva, 1958) (Conference on Problems of the Origin and Evolution of Comets and Other Small Bodies of the Solar System (Moscow, 1958)). — Voprosy Kosmogonii, Vol. 7, pp. 375–382. 1960.
6. KROPOTKIN, P. N. Znachenie paleomagnetizma dlya stratigrafii i geotektoniki (The Significance of Paleomagnetism for Stratigraphy and Geotectonics). — Byulleten' Moskovskogo Obshchestva Ispytatelei Prirody, No. 4. 1958.
7. LICHKOV, B. L. Dvizhenie materikov i klimaty proshlogo Zemli (Continental Movement and the Past Climate of the Earth). — Moskva-Leningrad, ONTI. 1935.
8. OPARIN, A. I. and V. G. FESENKOV. Zhizn' vo Vselennoi (Life in the Universe). — Moskva, Izdatel'stvo AN SSSR. 1956.
9. PEIVE, A. V. Obshchaya kharakteristika, klassifikatsiya i prostranstvennoe raspolozhenie glubinnykh razlomov. Glavneishie tipy glubinnykh razlomov (The General Description, Classification, and Location of Deep Breaks. The Main Types of Deep Breaks). — Article 1, Izvestiya AN SSSR, Seriya Geologicheskaya, No. 1. 1956.
10. PIKEL'NER, S. B. Evolyutsiya i dinamika Solntsa (The Evolution and Dynamics of the Sun). Article in this collection. See p. 104.
11. POLAK, I. F. Proiskhozhdenie Vselennoi (The Origin of the Universe). — Moskva-Leningrad, ONTI, Gostekhizdat. 1934.
12. PUTILIN, N. I. Malye planety (The Minor Planets). — Moskva, Gostekhizdat. 1953.
13. STRAKHOV, N. M. Tipy klimaticheskoi zonal'nosti v posleproterozoiskoi istorii Zemli i ikh znachenie dlya geologii (Types of Climatic Zonality in the Postproterozoic History of the Earth and the Significance of These for Geology). — Izvestiya AN SSSR, Seriya Geologicheskaya, No. 3. 1960.
14. STANYUKOVICH, K. P. K voprosy o proiskhozhdenii Solnechnoi sistemy (The Problem of the Origin of the Solar System). — Astronomicheskii Zhurnal, Vol. 29, No. 3. 1952.

15. FESENKOV, V. G. Postanovka problemy kosmogonii v sovremennoi astronomii (The Problem of Cosmogony in Contemporary Astronomy). — Astronomicheskii Zhurnal, 26, 2, 67. 1949.
16. FESENKOV, V. G. O proiskhozhdenii Solnechnoi sistemy (The Origin of the Solar System). — Izdatel'stvo Znanie, seriya 9, 1. 1960.
17. SHEINMANN, Yu. M. Platformy, skladchatye poyasy i razvitie struktury Zemli (Platforms, Wrinkled Belts, and the Development of the Earth's Structure). — Magadan, VNII, No. 1. 1959.
18. SHMIDT, O. Yu. Chetyre lektsii o teorii proiskhozhdeniya Zemli (Four Lectures on the Theory of the Origin of the Earth). — Moskva, Izdatel'stvo AN SSSR. 1957.
19. SHCHERBAKOV, D. I. — Vestnik Akademii Nauk, No. 4, p. 38. 1961.
20. MILNE, E. A. The Analysis of Stellar Structure. — Monthly Notices of the Royal Astronomical Society, 91, 4, London. 1930.

S.S. Gamburg

SOME REGULARITIES SHOWING SIMILARITY OF THE SOLAR AND PLANETARY SYSTEMS

Four basic regularities of the solar system having cosmogonic significance have been established:

1. All the planets revolve about the Sun along approximately circular orbits (ellipses).
2. All the planets revolve about the Sun in the same sense (counterclockwise).
3. The solar system is coplanar; the orbital planes of all the planets lie near the plane of the solar equator.
4. Angular momentum is so distributed in the solar system that, although the Sun contains 99.87% of the total mass and the planets a mere 0.13%, only 2% of the angular momentum is possessed by the Sun and 98% by the planets.

The planets are usually divided into two groups: the giant planets (Jupiter, Saturn, Uranus, and Neptune), and the terrestrial planets (Mercury, Venus, Earth, and Mars). Pluto is not included in either of these groups.

The mass of all the planets taken together constitutes only 1/1000 of the mass of the Sun. The mass of Jupiter, for instance, is 1/1100, the mass of the Earth is 1/320,000, and the mass of Mercury is 1/3,000,000 of the solar mass.

As a result of an analysis of these fundamental regularities, Shmidt concluded that the distribution of angular momentum in the solar system is of basic importance for solving the problem of the origin and evolution of the solar system. To solve the latter problem, Shmidt suggested the theory of the capture of a nebula by the Sun.

A recent hypothesis of Fesenkov* assumes that a nebula composed of gas and dust broke up into parts, which formed into the planets of the solar system. It is the opinion of the author of the present article that the basic mechanism responsible for the formation of planets and satellites was the interaction of the Sun and planets with the gas-dust nebulae which surrounded them during an early stage in their evolution.

The coplanarity of the solar system is the most fundamental of the above four regularities. The facts that the planets all revolve about the Sun in the same sense, that they follow nearly circular orbits, and that they possess most of the angular momentum in the solar system are all consequences of the coplanarity.

* Fesenkov, V.G. O proiskhozhdenii Solnechnoi sistemy (The Origin of the Solar System). — Izdatel'stvo "Znanie". 1960.

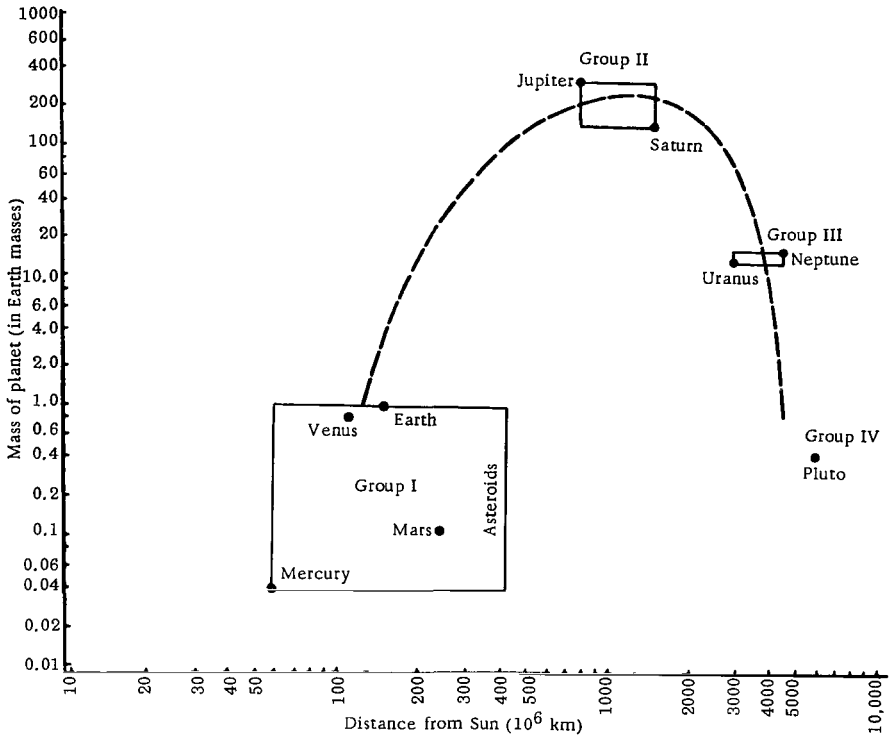


FIGURE 1. Mass distribution of the planets according to groups.

All the foregoing considerations apply to the planet-satellite systems in the solar system as well. Moreover, it is a fact that no one has noted previously a very important parameter of the systems of the Sun and the planets, and the planets and their satellites. The parameter here referred to is the regularity of the distances: 1) between planets and between groups of planets, and 2) between satellites and between groups of satellites.

We shall consider below the other regularities characteristic of the solar system. First, however, let us begin with a study of the satellite systems of the largest planets, Saturn and Jupiter, rather than with a study of the larger system of the Sun and the planets. Almost all the mass of the planets is concentrated in the two largest planets, the mass of Jupiter being equal to 317.37 Earth masses and the mass of Saturn being equal to 95.08 Earth masses (giving a total of 412.45 Earth masses).

Uranus (14.6 Earth masses) and Neptune (17.2 Earth masses) are much smaller, with a combined mass of 31.8 Earth masses. The total mass of the terrestrial planets (Mercury, Venus, Earth, and Mars), moreover, only amounts to 1.984 Earth masses.

The satellites of Jupiter can be grouped as follows, according to their distances from the planet and their equatorial diameters:

		Distance from Jupiter (km)	Equatorial diameter (km)
Group I	1. Amalthea (V)	181,000	160 (?)
	2. Io (I)	421,800	3550
	3. Europa (II)	671,400	3100
Group II	4. Ganymede (III)	1,071,000	5600
	5. Callisto (IV)	1,884,000	5050
Group III	6. VI	11,500,000	160
	7. VII	11,730,000	56
	8. X	11,750,000	24
Group IV	9. XII	21,000,000	30
	10. XI	22,500,000	30
	11. VIII	23,500,000	56
	12. IX	23,700,000	27

As shown in the table, the satellites of Jupiter can be divided into four groups, on the basis of their distances from the planet.

The first group (Amalthea, Io, and Europa) lie at distances of 100,000 to 700,000 km from the planet. The second group (Ganymede and Callisto) are between one and two million km away, and it is interesting to note that these two are the largest Jovian satellites. Later, when we consider the satellite systems of other planets, we shall see that this constitutes a definite regularity which is significant with respect to the cosmogony of the solar system. The third group (satellites VI, VII, and X) are situated within a small spatial interval between 11,300,000 and 11,750,000 km from Jupiter. Finally, the fourth group (satellites XII, XI, VIII, and IX) lie at distances from 21,000,000 to 23,700,000 km from the planet. All four of the satellites in this group have retrograde motions.

Amalthea, the satellite closest to Jupiter, is 181,000 km from the planet, an important fact which will be discussed later. The table shows that the distances between satellites and the satellite masses in the first group increase. It may be that between Amalthea and Io either there were or there ought to be two more satellites, larger than Amalthea and smaller than Io.

The distance between the first and second groups (that is, between Europa and Ganymede) is 399,600 km, and the distance between Ganymede and Callisto (that is, between the satellites in the second group) is about twice this value (813,000 km).

The second and third groups of Jovian satellites are separated by 9,616,000 km, and the distance between the adjacent satellites of the third and fourth groups (9,250,000 km) is about the same [see table on inset page].

Next, let us consider the inclinations of the satellite orbits with respect to the planetary orbit and the planetary equator (see table on following page).

		Group I			Group II		Group III			Group IV			
		Amalthea	Io	Europa	Ganymede	Callisto	VI	VII	X	XII	XI	VIII	IX
Inclination of orbit	to planetary orbit	3°7'	3°7'	3°6'	3°2'	2°43'	28°45'	27°58'	28°24'	147°3'	163°37'	148°4'	156°
	to planetary equator	0°0'	0°0'	0°0'	0°0'	4°0'	31°	30°	—	145°	—	145°	154°

The further away from the planet the satellites are, the greater are the inclinations of their orbits. This is particularly noticeable for the third and fourth groups.

Now let us compare the densities of the terrestrial planets with the densities of the first group of Jovian satellites:

Terrestrial planets		Jovian satellites	
name	density	name	density
Mercury	5.7		
Venus	4.94		
Earth	5.516		
Mars	3.99	Io	3.22
Asteroids	3.7(?)	Europa	3.15

As the table shows, the satellites in the first satellite groups of the two largest bodies in the solar system (the Sun and Jupiter) have nearly identical densities. Thus it may be assumed that the physical situation on the primary, as well as the chemical processes taking place there, were of a similar nature during the evolutionary stages of the Sun and Jupiter in which their first satellite groups were formed.

If the asteroids are considered to represent a fifth, fragmented planet in the first group of the Sun, then the density of this hypothetical planet (3.7) can be compared to that of the Jovian satellite Europa (3.15).

When all these data are studied separately just for the Jupiter system, they are not particularly striking. However, a comparison with the data for the system of Saturn, the second giant planet in the solar system, leads us to draw the following conclusion: certain regularities in the solar system exist which have not as yet been recognized.

Now let us consider the satellite system of Saturn. As the table compiled by the author shows [see inset page], the satellites of Saturn can be divided into four groups in the same way as were the Jovian satellites.

The first group has five members, located (like the first group of Jovian satellites) at distances from 100,000 to 700,000 km from the planet.

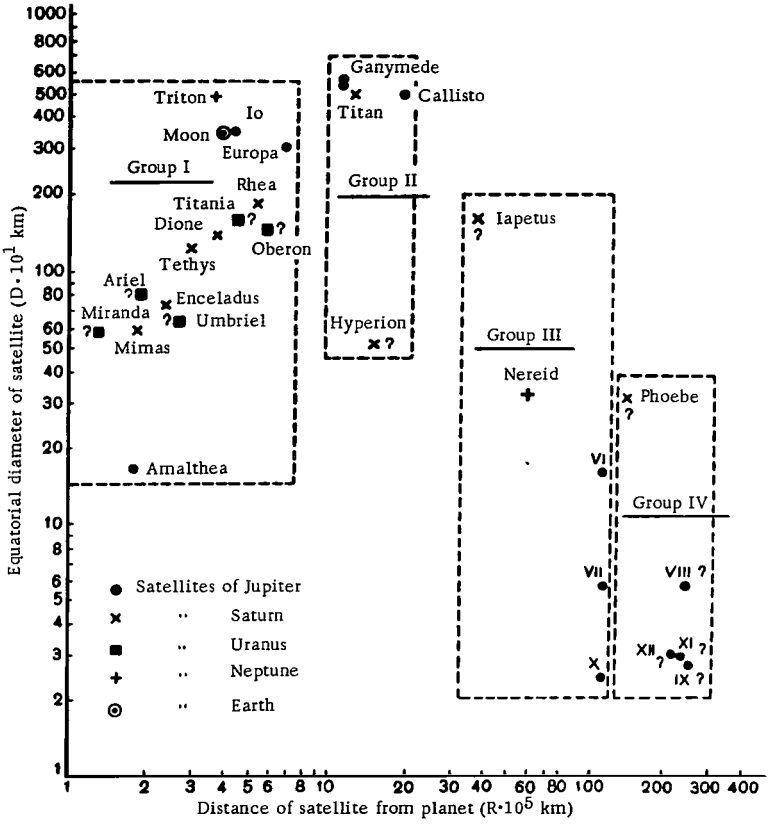


FIGURE 2. Relative graph of satellite diameter (in 10 km) plotted against satellite distance from central body (in 10^5 km).

	Mimas	Enceladus	Tethys	Dione	Rhea
Distance from planet, km	185,600	238,100	294,800	377,500	527,200
Distance between satellites, km	52,500		56,700	82,700	149,700
Equatorial diameter, km	590	740	1200	1400	1850

The distances between the satellites in this group are found to increase consistently with the distance from the planet, and the same is true of the equatorial diameters of the satellites. Finally, the inclinations of the orbits of these five satellites also indicate that they should be members of a single group:

Inclination of orbit	Mimas	Enceladus	Tethys	Dione	Rhea
To planetary orbit	26°44'	26°44'	26°44'	26°44'	26°42'
To planetary equator	1.5°	0.0°	0.1°	0.0°	0.3°

Let us now compare the first satellite groups in the systems of Jupiter and Saturn. The following analogous regularities are observed for these two groups.

1) The first satellite groups of both systems have the same range of distances from the center of the system, that is, they are located from 100,000 to 700,000 km from the planet.

2) In both systems the closest satellite is located about the same distance away from the planet: Amalthea is 181,000 km from Jupiter, and Mimas is 185,600 km from Saturn.

3) In both systems the distances between the first-group satellites increase with the distance from the planet.

4) The sizes of the satellites also increase with the distance from the planet.

The first group of the Jupiter system contains three satellites, and that of the Saturn system contains five. If we assume that the Sun and the planets evolved according to a process which was similar to that according to which the planetary satellites were formed, then it is very likely that the first group of Jupiter also contains five members.

Let us now consider the second satellite group of Saturn, which contains Titan (VI) and Hyperion (VII), and let us compare it with the second group of Jovian satellites.

Like the second group of Jupiter, the second group of Saturn is located between one and two million km from the planet. The following table compares the characteristics of the two satellite groups.

	Jupiter		Saturn	
	Ganymede	Callisto	Titan	Hyperion
Mean distance from planet, 10^3 km	1071	1884	1222	1481
The same, in planetary radii	15.04	26.47	20.38	24.70
Distance between satellites, 10^3 km	813		259	
Mass of satellite (in planetary masses)	1/12,520	1/22,200	1/4700	1/4,500,000
Equatorial diameter, km	5600	5050	4950	500 (?)
Density	2.25	1.56	2.34	1.6 (?)
Inclination of orbit to planetary orbit	3°2'	2°43'	26°7'	26°0'
Inclination of orbit to planetary equator	0.0°	4.0°	0.3°	0.6°

Titan, the largest satellite in the Saturn system, is a member of the second group of this system. This may be compared with the Jupiter system, in which the two largest satellites (Ganymede and Callisto) are in the second group. Such a comparison shows that, with respect to size, the other satellite in the second group of Saturn, Hyperion, constitutes an exception. In general, however, a comparison of the data for the second groups of Jupiter and Saturn indicates that the satellites in these groups have similar parameters.

So far, the third group of the Saturn system has only one known member, Iapetus. This satellite lies at a distance of 3,562,000 km from

the planet. The fourth group of this system also has only one known member, Phoebe, which is 12,961,000 km away from Saturn. The distance between Iapetus and Phoebe is 9,399,000 km, a figure comparable to the distance between the third and fourth groups of the Jupiter system (9,250,000 km).

It is interesting that Phoebe, the fourth-group satellite of the Saturn system, is similar to all four fourth-group satellites of the Jupiter system in that it has retrograde motion. This is another indication of the overall regularity in the formation of the fourth-group satellites for the two planets.

It is thus likely that there are more satellites in the third and fourth groups of the Saturn system, in addition to Iapetus and Phoebe.

Now that we have compared the satellite systems of the two giant planets, we see that there is in fact a great similarity between them. The salient points of this similarity are as follows:

1. Both systems can be divided into four satellite groups.
2. The first and second groups are located within the same ranges of distance from the planet.
3. The second groups of both systems contain two members each, these being (with the exception of Hyperion) the largest satellites in the systems.
4. The distances between the third and fourth groups of both systems are about the same (9,250,000 and 9,399,000 km).
5. The satellites in the fourth groups of both systems have retrograde motions.
6. For the fourth satellite groups of both systems, the inclinations of the orbits with respect to the planetary orbit and the planetary equator are greater than the inclinations for the other satellite groups.
7. The closest satellites in these two systems (Amalthea and Mimas) lie at nearly the same distances from their planets.
8. In both systems there is an increase in the mass of the satellites and in the distance between satellites for the first group, as we move outward from the planet.
9. In both systems the densities of the second-group satellites are about the same: Ganymede, 2.25; Titan, 2.34; Callisto, 1.56; Hyperion, 1.6 (?).

Consequently, in these two systems the same regularities exist with respect to the distribution of matter according to zones, according to the distances from the centers of the systems, and according to the sizes of the satellites. This all goes to show that the satellites in question were formed in groups. The foregoing data also indicate that these two planets passed through the same four evolutionary stages, leading in each case to the formation of four satellite groups.

The systems of the other two comparatively large planets, Uranus and Neptune, have not yet been studied properly, since these planets are far from the Earth. However, the data which are already available indicate that the same regularities exist in these systems as in the systems of Jupiter and Saturn. For example, the known satellites of Uranus conform to the same rule as the first satellite groups of Jupiter and Saturn. As regards Neptune, however, only two satellites have as yet been discovered, so that it is too early to evaluate the structure of this system.

We shall conclude our study of the planetary systems by considering the Earth and Mars, the remaining two planets possessing satellites, no satellites of Mercury, Venus, or Pluto having been discovered so far.

First let us consider the system of Mars. The two Martian satellites, Phobos and Deimos, lie quite close to the planet: Phobos is 9400 km away, and Deimos is 23,500 km away. These two satellites are both very small, being comparable in size to asteroids: Phobos has a diameter of 16 km and Deimos has a diameter of 8 km.

The orbital inclinations of these satellites to the orbit and equator of the planet are approximately the same as the inclinations of the satellites of Saturn in groups I, II, and III.

		Phobos	Deimos
Inclination of orbit	to planetary orbit	27°29'	27°25'
	to planetary equator	1°4'	2°

The Earth has one satellite, the Moon, lying 384,000 km away from it. The data for the Moon are as follows: mass, 1/81.5 of the mass of the Earth; equatorial diameter, 3476 km; inclination of orbit to planetary orbit, 5°9'; inclination to planetary equator, 18°18'; and density, 3.34. With respect to distance from planet and equatorial diameter, the Moon should belong to the first group. However, this system undoubtedly constitutes an anomaly, because of the very large size and mass of the satellite relative to the primary.

Now let us consider the system of the Sun and the planets, and let us see whether the same regularities as were observed for the planet-satellite systems exist in this larger system. When we arrange the planets according to their distances from the Sun, we see that the planets (or solar satellites) fall into four groups. The first group contains Mercury, Venus, Earth, Mars, and the asteroids (a fragmented planet). The table shows the relevant characteristics for this group of planets.

	Mercury	Venus	Earth	Mars	Asteroids
1. Distance from Sun, 10^6 km	57.87	108.14	149.50	227.79	420.0
2. Distance between planets, 10^6 km	50.27	41.36	78.29	192.3	
3. Equatorial diameter, km	4770	12,350	12,756	6740	
4. The same (Earth = 1)	0.37	0.969	1.000	0.529	
5. Volume (Earth = 1)	0.052	0.910	1.00	0.148	
6. Mass (Earth = 1)	0.0543	0.8136	1.00	0.1069	0.1 of Earth
7. Density (Earth = 1)	1.03	0.90	1.00	0.72	
8. Density (water = 1)	5.7	4.94	5.516	3.99	
9. Inclination	7°004'	3°394'	0°	1°850'	

These four planets should be placed in one group. Moreover, if the asteroids are considered to be a fragmented planet, the first satellite

		Symbol	Units	First group, terres				
SUN-PLANET SYSTEM	1. Planet			Mercury		Venus		Eart
	2. Distance from Sun	R	10^6 km	57.87		108.14		149
	3. Distance between planets	r	10^6 km		50.27		41.36	
	4. Equatorial diameter	d	km	4770		12,350		12,7
	5. The same, relative to Earth			0.37		0.969		1.00
	6. Volume (Earth = 1)	V		0.052		0.910		1.00
	7. Mass (Earth = 1)	m		0.0543		0.8136		1.00
	8. Density relative to Earth			1.03		0.90		1.00
	9. Density	P	g/cm^3	5.7		4.94		5.51
	10. Inclination	i		7.004		3.394		—
				First gr				
JUPITER SYSTEM	1. Satellite			Amalthea V		?		?
	2. Mean distance from planet	R	10^3 km	181				
	3. The same, in planetary radii			2.56				
	4. Distance between satellites	r	10^3 km				240.8	
	5. Satellite mass rel. to planet	m		?				
	6. Equatorial diameter	d	km	160				
	7. Volume	V		—				
	8. Density	P	g/cm^3	—				
	9. Inclination of orbit to plan. orbit	i	—	3°7'				
	10. The same, to plan. equator		—	0.0				
				First gr				
SATURN SYSTEM	1. Satellite			Mimas I		Enceladus II		Tethy
	2. Mean distance from planet	R	10^3 km	185.6		238.1		294.8
	3. The same, in planetary radii			3.10		3.97		4.92
	4. Distance between satellites	r	10^3 km		52.500		56.700	
	5. Satellite mass rel. to planet	m		1/16,340,000		1/4,000,000		1/921,
	6. Equatorial diameter	d	km	590		740		1200
	7. Volume	V		?		—		—
	8. Density	P	g/cm^3	0.6?		0.98		1.60
	9. Inclination of orbit to plan. orbit	i		26°44'		26°44'		26°44'
	10. The same, to plan. equator			1.5		0.0		0.1
	Rings of Saturn			Dist. from planet 90,000 to 138,000 km. In plan. radii 1.				
				First gr				
URANUS SYSTEM	1. Satellite			Miranda V**		Ariel I**		Umbri
	2. Mean distance from planet	R	10^3 km	130.4		191.9		267.3
	3. The same, in planetary radii			5.11		1.52		10.48
	4. Distance between satellites	r	10^3 km		61.5	—	75.4	
	5. Satellite mass rel. to planet	m		—		—		—
	6. Equatorial diameter	d	km	—		800(?)		640(?)
	7. Volume	V		—		—		—
	8. Density	P	g/cm^3	—		—		—
	9. Inclination of orbit to plan. orbit	i		98°		97°59'		97°59'
	10. The same, to plan. equator					0		0
				First gr				
NEPTUNE SYSTEM	1. Satellite			?		?		?
	2. Mean distance from planet	R	10^3 km					
	3. The same, in planetary radii							
	4. Distance between satellites	r	10^3 km					
	5. Satellite mass rel. to planet	m						
	6. Equatorial diameter	d	km					
	7. Volume	V						
	8. Density	P	g/cm^3					
	9. Inclination of orbit to plan. orbit	i						
	10. The same, to plan. equator							

First group, terrestrial (metallic)								Second group, hydrogen			
	Venus		Earth		Mars		Asteroids		Jupiter		Saturn	
	108.14		149.50		227.79		420.0		777.8		1426.1	
50.27		41.36		78.29		192.3		357.8		648.3		14
	12,350		12,756		6470		?		142,550		119,500	
	0.969		1.000		0.529				11.19		9.38	
	0.910		1.00		0.148				1.314		744	
	0.8136		1.000		0.1069		1/10 Earth		317.37		95.08	
	0.90		1.00		0.72				0.24		0.13	
	4.94		5.516		3.93				1.33		0.71	
	3.394		—		1.850				1.306		2.491	
First group									Second group			
	?		?		Io (I)		Europa II		Ganymede III		Callisto IV	
					421.8		671.4		1071		1884	
					5.94		9.44		15.04		26.47	
		240.8				249.5		399.6		813		9
					1/22,240		1/39,430		1/12,520		1/22,200	
					3550		3100		5600		5050	
					—		—		—		—	
					3.22		3.15		2.25		1.56	
					3°7'		3°6'		3°2'		2°43'	
					0.0		0.0		0.0		4.0	
First group									Second group			
	Enceladus II		Tethys III		Dione IV		Rhea V		Titan VI		Hyperion VII	
	238.1		294.8		377.5		527.2		1222.0		1481.0	
	3.97		4.92		6.30		8.79		20.38		24.70	
52.500		56.700		82.700		149.700		694.8		259	1/4,500,000	2
	1/4,000,000		1/921,500		1/526,000		1/250000		1/4700		500 (?)	
	740		1200		1400		1850		4950			
	—		—		—		—		—		1.6?	
	0.98		1.60		3.24		0.15		2.34		26°0'	
	26°44'		26°44'		26°44'		26°42'		26°7'		0.6	
	0.0		0.1		0.0		0.3		0.3			
net 90,000 to 138,000 km. In plan. radii 1.48-2.29. Inclin. of orbit { to plan. equat., 0° / to plan. orbit, 28°6'												
First group									Second group			
	Ariel I**		Umbriel II**		Titania III**		Oberon IV**		?		?	
	191.9		267.3		439.2		587.0					
	1.52		10.48		17.21		23.01					
61.5	—	75.4		171.9								
	—		—		—		—					
	800(?)		640(?)		1600(?)		1450(?)					
	—		—		—		—					
	—		—		—		—					
	97°59'		97°59'		97°59'		97°59'					
	0		0		0		0					
First group									Second group			
	?		?		Triton*		?		?		?	
					353.7							
					12.9							
					1/290							
					4800							
					4.7							
					139°49'							
					20°							

Third group, Uranian						Fourth group, Plutonian						
Uranus 2869.1 48,230 3.78 54 14.61 0.26 1.49 0.773		1626.6		Neptune 4495.7 45,550 3.58 46 17.23 0.38 2.09 1.774	1409.3	Pluto 5905.0 12,700? 1 ? 1 ? 0.8 ? 0.8 , ? 4.4 ? 17.144		?		?		?
Third group						Fourth group						
VI 11,500 160.4 ? 160 — — 28°45' 31°		250	VII 11,750 165.4 ? 56 — — 27°58' 30°		X 11,750 165.4 ? 24 — — 28°24' —	9.250	XII* 21.000 296.0 ? 30(?) — — 147°3' 145°	1.500	XI* 22.500 316.7 ? 30 — — 147°3' 145°	1.000	VIII* 23.500 330.7 ? 56 — — 148°4' 145°	200	IX* 23.700 338.0 ? 27 — — 156° 154°
Third group						Fourth group						
apetus VIII 3562.0 59.41 1/100,000 1600(?) — 1.15 16°18' 14°			?		?	9399.0	Phoebe IX* 12,961 216.2 320 (?) — — 174°42' 30°		?		?		?
Mass of rings, in units of mass of planet, 1/3000												
Third group						Fourth group						
?			?		?		?		?		?		?
Third group						Fourth group						
?			?		?	5,216,300	Nereid 5,570,000 200 1/1,160,000 320 2.4 5-6° —		?		?		?

Third group						Fourth group					
Iapetus VIII		?		?		Phoebe IX*		?		?	?
3562.0						12,961					
59.41					9399.0	216.2					
1/100,000						320 (?)					
1600(?)						—					
—						—					
1.15						174°42'					
16°18'						30°					
14°											

Mass of rings, in units of mass of planet, 1/3000

Third group						Fourth group					
?		?		?		?		?		?	?

Third group						Fourth group					
?		?		?		Nereid		?		?	?
						5,570,000					
	5,216,300					200					
						1/1,160,000					
						320					
						2.4					
						5-6°					
						—					

* Retrograde motion

** Retrograde motion, corresponding to sense of rotation of Uranus

FIGURE 3. Regularities showing similarity between solar and planetary systems.

Notes: 1. The group of terrestrial planets (Mercury, Venus, Earth, and Mars) is called the "metallic" group, since these planets contain a large amount of heavy metals.

2. The second group of planets, Jupiter and Saturn, is called the "hydrogen" group, since the planets of this group contain a large amount of hydrogen (Jupiter, 85%; Saturn, 50%).

3. The third group of planets, Uranus and Neptune, is called arbitrarily the "Uranian" group, after the planet Uranus. There is less hydrogen in these planets than in Jupiter and Saturn.

4. The fourth group, comprising Pluto and the planets which will be discovered beyond Pluto, is called arbitrarily the "Plutonic" group, after the planet Pluto.

5. Question marks are introduced wherever, according to the opinion of the author, planets and planetary satellites should exist.

					Second group					Third group				
	Dione IV		Rhea V		Titan VI		Hyperion VII			Iapetus VIII		?		
	377.5		527.2		1222.0		1481.0			3562.0				
	6.30		8.79		20.38		24.70			59.41				
00		149.700		694.8		259	1/4,500,000		2081.0					
	1/526,000		1/250000		1/4700		500 (?)			1/100,000				
	1400		1850		4950					1500(?)				
	—		—		—		1.6?			—				
	3.24		0.15		2.34		26°0'			1.15				
	26°44'		26°42'		26°7'		0.6			26°18'				
	0.0		0.3		0.3					14°				
nclin. of orbit	to plan. equat., 0°									Mass of rings, in units of				
	to plan. orbit, 28°6'													
					Second group					Third group				
	Titania III**		Oberon IV**		?		?			?		?		
	439.2		587.0											
.9	17.21		23.01											
	—		—											
	1600(?)		1450(?)											
	—		—											
	—		—											
	97°59'		97°59'											
	0		0											
					Second group					Third group				
	Triton*		?		?		?			?		?		
	353.7													
	12.9										5,216,300			
	1/290													
	4800													
	4.7													
	139°49'													
	20°													
	Moon		?											
	384.4													
	60.27													
	1/81.5													
	3476													
	0.020													
	3.33													
	5°9'													
	1.8													

* Retrograde mo
** Retrograde mo

FIGURE 3. Regu

Notes: 1. Th
group, since the
2. Th
planets of this g
3. Th
after the planet
4. Th
called arbitrari
5. Qu
planetary satell

	10. The same, to plan. equator			0.0					
				First gro					
SATURN SYSTEM	1. Satellite			Mimas I		Enceladus II		Tethys	
	2. Mean distance from planet	R	10^3 km	185.6		238.1		294.8	
	3. The same, in planetary radii			3.10		3.97		4.92	
	4. Distance between satellites	r	10^3 km		52.500		56.700		
	5. Satellite mass rel. to planet	m		1/16,340,000		1/4,000,000		1/921,5	
	6. Equatorial diameter	d	km	590		740		1200	
	7. Volume	V		?		—		—	
	8. Density	P	g/cm^3	0.6?		0.98		1.60	
	9. Inclination of orbit to plan. orbit	i		26°44'		26°44'		26°44'	
	10. The same, to plan. equator			1.5		0.0		0.1	
	Rings of Saturn			Dist. from planet 90,000 to 138,000 km. In plan. radii 1.4					
				First gro					
URANUS SYSTEM	1. Satellite			Miranda V**		Ariel I**		Umbriel	
	2. Mean distance from planet	R	10^3 km	130.4		191.9		267.3	
	3. The same, in planetary radii			5.11		1.52		10.48	
	4. Distance between satellites	r	10^3 km		61.5	—	75.4		
	5. Satellite mass rel. to planet	m		—		—		—	
	6. Equatorial diameter	d	km	—		800(?)		640(?)	
	7. Volume	V		—		—		—	
	8. Density	P	g/cm^3	—		—		—	
	9. Inclination of orbit to plan. orbit	i		98°		97°59'		97°59'	
	10. The same, to plan. equator					0		0	
				First gr					
NEPTUNE SYSTEM	1. Satellite			?		?		?	
	2. Mean distance from planet	R	10^3 km						
	3. The same, in planetary radii								
	4. Distance between satellites	r	10^3 km						
	5. Satellite mass rel. to planet	m							
	6. Equatorial diameter	d	km						
	7. Volume	V							
	8. Density	P	g/cm^3						
	9. Inclination of orbit to plan. orbit	i							
	10. The same, to plan. equator								
				First gr					
EARTH SYSTEM	1. Satellite			?		?		?	
	2. Mean distance from planet	R	10^3 km						
	3. The same, in planetary radii								
	4. Distance between satellites	r	10^3 km						
	5. Satellite mass rel. to planet	m							
	6. Equatorial diameter	d	km						
	7. Volume	V							
	8. Density	P	g/cm^3						
	9. Inclination of orbit to plan. orbit	i							
	10. The same, to plan. equator								
				First group					
MARS SYSTEM	1. Satellite			Phobos			Deimos		
	2. Mean distance from planet	R	10^3 km	9.4			23.5		
	3. The same, in planetary radii			2.77			6.96		
	4. Distance between satellites	r	10^3 km		14.1				
	5. Satellite mass rel. to planet	m		10^{-8}			10^{-9}		
	6. Equatorial diameter	d	km	16			8		
	7. Volume	V		—			—		
	8. Density	P	g/cm^3	—			—		
	9. Inclination of orbit to plan. orbit	i		27°29'			27°25'		
	10. The same, to plan. equator			1°4'			2°		

group of the Sun will contain five members, the same number as the first group of the system of Saturn. The distances between the planets gradually increase with increasing distance from the Sun, a situation similar to that observed in the systems of the giant planets.

The second group in the solar system contains the two very large planets Jupiter and Saturn. It is noteworthy that the second groups in the systems of Jupiter and Saturn also each have two satellites in them, and that these (with the exception of Hyperion) are the largest in each system. It is thus likely that this constitutes a general regularity for both the system of the Sun and the systems of the planets, although exceptions do exist.

The following table lists the basic characteristics of Jupiter, Saturn, Uranus, and Neptune.

	Jupiter	Saturn	Uranus	Neptune
1. Distance from Sun, 10^6 km ...	777.8	1,426.1	2,869.1	4,495.7
2. Distance between planets, 10^6 km	648.3	1443.0	1626.6	
3. Equatorial diameter, km	142,550	119,500	48,230	45,550
4. The same (Earth = 1).....	11.19	9.38	3.78	3.58
5. Volume (Earth = 1)	1,314	744	54	46
6. Mass (Earth = 1)	317.37	95.08	14.61	17.23
7. Density (Earth = 1)	0.24	0.13	0.26	0.38
8. Density (water = 1).....	1.33	0.71	1.49	2.09
9. Inclination	1°306'	2°491'	0°773'	1°774'

It is the opinion of the author that, with respect to size, mass, and chemical composition, Uranus and Neptune constitute an independent, third group of planets of the solar system. This is corroborated by the fact that from Venus out to Saturn the distances between planets consistently increase, whereas from Saturn to Pluto these distances remain about the same (1.5 billion km, on the average).

Pluto, which is 5.905 billion km from the Sun, has been studied less than the other planets. Its diameter is approximately half that of the Earth. Different explanations have been suggested for the origin of Pluto. For instance, it has been proposed that Pluto was captured by the Sun as an already-formed planet, that it is a former satellite of Neptune, and that it is a large member of a second asteroid belt located beyond Neptune.

By virtue of the existence of four satellite groups in the systems of Jupiter and Saturn, the author is led to the assumption that the Sun also has four groups of satellites (planets), and that Pluto belongs to the fourth group.

Consequently, it is possible that other planets belonging to this fourth group exist beyond Pluto. If the regularity of the distances between planets continues to be observed further out, then the next planet beyond Pluto ("Transpluto") should be 1.5 billion km from Pluto (about 50 astronomical units from the Sun). The inclination of the orbit of this planet should be approximately the same as that of Pluto, and the planet should be smaller in size than Pluto.

An analysis of the regularities existing in the system of the Sun and its satellites (planets) has led the author to conclude that these regularities are analogous to those of the systems of Jupiter and Saturn. A complete classification of the distribution of matter throughout the solar system, according to zones, is presented in the table on the inset page. We assume that the following things are possible: 1) the existence of planets beyond Pluto; 2) the presence of satellites between Io and Europa in the first group of Jupiter; 3) the presence of outer satellites of Saturn in addition to Iapetus and Phoebe; 4) the existence of additional satellites of Uranus and Neptune, especially in the first group of Neptune, and also in the group of Nereid and in the other places in the table where we have placed question marks.

A study of this table brings up several important questions, and any adopted cosmogonic hypothesis concerning the origin and evolution of the solar system must find answers to them. In particular, how can we explain the existence of four groups of satellites in each of the main systems of the solar system (the systems of the Sun, Jupiter, and Saturn)? Moreover, if this is related to the fact that the Sun and the planets went through the same four stages during their development, then what were the stages and how did they differ from one another? What types of nuclear reactions took place in the Sun and what processes occurred on the planets during each of these four stages? Why are the planetary satellites of the first and second groups located within definite spatial intervals from their planets, and why is it that the second groups have two members, the largest satellites in the system? Finally, how can we explain the fact that approximately the same distances separate the third and fourth groups of the Jupiter and Saturn systems? There are also several other questions which come up, but the answers to these require a further development of our cosmogonic concepts, and this is difficult to accomplish within the framework of the present article.

S. B. Pikel'ner

THE EVOLUTION AND DYNAMICS OF THE SUN

The Sun's bright surface, the photosphere, is an opaque layer of incandescent gas at a temperature of about 5800°K* and with a density of about 10^{-7} g/cm^3. The properties of the deeper layers can only be theoretically calculated, on the basis of conditions of hydrostatic equilibrium, thermal equilibrium (constancy of temperature at any given point), and local thermodynamic equilibrium. These conditions, expressed in the form of a set of differential equations, make it possible to compute the distribution of the properties of the gas with depth, given the chemical composition of the gas (the relative content of hydrogen, helium, and heavy elements), the conditions on the outer boundary, and some additional parameters. The calculation also includes the energy released in the nuclear reactions taking place at the high temperature and density prevailing in the Sun's inner core. The first reaction involves the fusion of two hydrogen nuclei, which form deuterium and a positron. In the process gamma rays are given off. The deuterium nucleus quickly captures a proton, turning into the He^3 isotope, and then two He^3 nuclei fuse, transforming into He^4 and two protons. In the course of these reactions a large amount of energy is released, which gradually diffuses outward in the form of radiation quanta. The mean wavelength of the radiation depends on the temperature; in the interior it falls within the X-ray range, while at the surface visible light emerges.

The rate at which energy is released depends on the temperature and density at the center, and in a star of normal constitution it is ultimately determined by the mass. Under the conditions existing inside the Sun, it will take about 7 billion years for the hydrogen in the central region to transform almost completely into helium. At present more than half of the hydrogen originally contained in this region has been transformed into helium. The composition of the middle and surface layers has apparently remained the same as it was when the Sun was formed. The increasing helium content in the core makes the mean molecular weight of the gas higher, and that causes the temperature at the center to rise. At present the temperature there is about 13 million degrees. The rate of the reactions strongly depends on the temperature, and thus the Sun's radiation is growing stronger, even though the relative content of hydrogen is decreasing. Calculations show that during its existence (about 5 billion years) the brightness of the Sun has risen by about 60%. Accordingly, in the course of the last billion years the radiant energy received by the Earth has increased by about 10% and there has been a rise in the Earth's mean temperature. It is a fact, though, that the temperature of the Earth depends to a large extent on factors such as the atmospheric composition and circulation, and

* Here and in the following, the temperatures are given in degrees Kelvin, the zero point of which is absolute zero (-273°C).

it is therefore difficult to obtain a precise value for the net rise in temperature.

As the hydrogen in the center of the Sun becomes depleted, a core of high molecular weight is formed. This core, deprived of energy sources, will start contracting until it goes into a state of degeneracy in which the contraction will almost cease. There will be no energy release either in the core or in the outer portion of the Sun, but only at the boundary of the core, where some hydrogen will have remained and the temperature will be sufficiently high. The size of the outer portion of the Sun will slowly increase, and the Sun will eventually turn into a red giant. At that time the temperature of the Earth will have reached about 1000°K. The Sun's envelope will gradually expand and transform into a planetary nebula (Figure 1), while the core will become a small dense hot star, i.e., a white dwarf.

FIGURE 1

At an early stage of its development the Sun was apparently a contracting gas sphere. It might have possibly been formed from the central part of the same cloud of gas and dust from which the planets were produced. The main argument against the nebular hypothesis of the formation of the Sun and planets has been the fact that the specific angular momentum of the Sun is too small, only 1/50,000 of that of the planets, per unit mass. It has been found, however, that in the presence of a magnetic field momentum could be transferred from the central part of the cloud to the disk. The lines of force are twisted by the rapidly rotating central condensation and slow it down, and at the same time they speed up the rotation of the disk. This effect is apparently associated with the fact that, beginning with the F class, stars have a slow rotation, much slower than should be the rotation of a body condensed from a relatively rarefied medium which possesses even a very small momentum. This suggests that most stars of the main sequence may have planetary systems or gas-dust disks.

Let us now turn back to the present state of the Sun. The energy diffusing from the interior does not produce in most of the solar body any macroscopic motions. However, in the layer underlying the surface, to a depth of about 0.1 solar radii, convective motions arise. The appearance of convection in that particular layer is caused by partial ionization of the hydrogen. The ionization changes with temperature variations of the gas, which is equivalent to an increase in heat capacity facilitating convection. In the deeper layers the hydrogen is fully ionized, but convection may be sustained by partially ionized helium. At greater depths convection ceases. In the main part of the convection zone heat transfer is effected not by radiation but by ascending and descending currents. Only in the uppermost, photospheric layers, where the transparency of the gas is higher, the convective energy transfer is sharply reduced.

In the convection zone, at least in its upper layers, individual cells are formed, in which the gas rises along the centerline and sinks along the border. These cells, or rather streams of gas, which move across the photosphere, appear as brilliant patches—granules—which cover the whole solar surface. The granules appear and disappear within a few minutes. Their temperature is several hundred degrees higher than that of the darker areas between them.

The motions in the upper layers of the convection zone produce contractions and expansions of the gas. These disturbances are propagated in the form of sound waves into the higher layers of the solar atmosphere.

As the waves advance into a medium of lower density, their amplitude increases and thus the sound waves gradually turn into shock waves. The shock waves damp out fairly rapidly, and their energy is converted into heat. The upper atmosphere of the Sun is continuously heated in this way by the waves coming up from the underlying convection zone. This is responsible for certain anomalous properties displayed by the upper layers of the atmosphere.

The radiation of the visible surface of the Sun has a continuous spectrum with dark absorption lines. When the Sun's disk is eclipsed by the Moon, the chromosphere is visible around it as a thin crescent, whose spectrum is mainly composed of bright lines.

The thickness of the chromosphere is about 10,000 km. Above it extends the tenuous corona (Figure 2), from which streamers stretch out to a distance of some tens of solar radii. The great extent of the streamers has been a mystery for a long time, and it now appears that the explanation is connected with the flux of energy from below.

The temperature that the gas attains by the heating depends also on the process by which the gas is cooled. The solar gas cools down by self-radiation; electrons lose thermal energy by exciting atoms which in turn emit radiation quanta into space. The emission of the transparent gas layer depends on its density—the higher the density the more frequently collisions occur, and thus the more intense is the emission of the gas and the stronger the cooling. The rarefied corona radiates very little, and is consequently heated by the waves to a very high temperature, exceeding a million degrees. The upper layers of the chromosphere, being denser, are cooled more, so that the temperature there only goes up to 10,000 or 20,000°K. The lower layers of the atmosphere radiate so intensely that they gain no heat from the waves. Accordingly, the corona is very hot because it is so tenuous and emits little radiation. This is why its high temperature does not affect

the Sun's emission in the visible portion of the spectrum, and thus the temperature of the Sun is said to be close to 5800°. If the corona were denser, it would radiate more intensely. But then its temperature would be lower and it would not be a corona.

The statement that the corona is transparent is not quite correct. In certain ranges of the short-wave X-ray region and for radio waves longer than a meter the corona is opaque, and consequently within these ranges it radiates like a black body with a temperature of more than a million degrees.

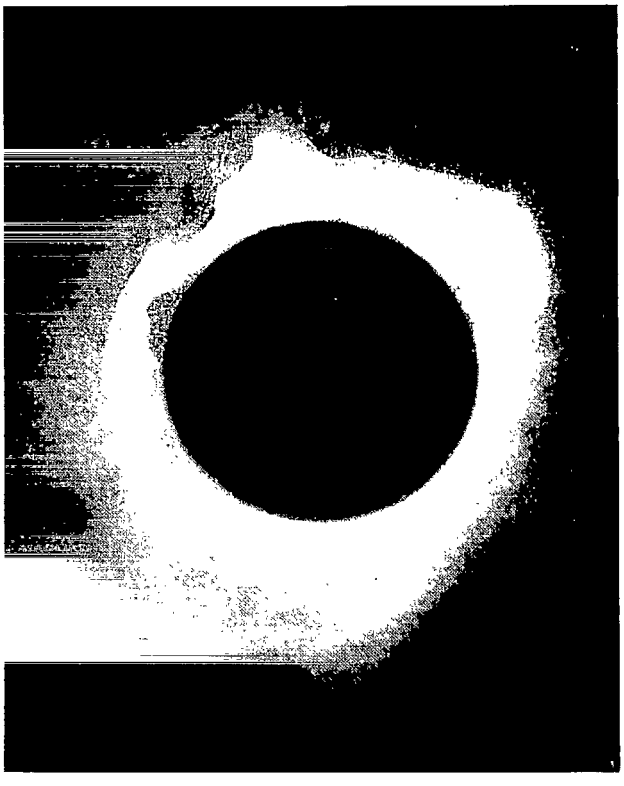


FIGURE 2

In the longer-wavelength region, the ultraviolet, the emission of the corona is low, but the chromosphere is still opaque and radiates relatively strongly. Thus, the short-wave and radio regions of the spectrum are emitted not by the relatively cool photosphere, but by the hotter upper layers of the solar atmosphere. If the corona and the chromosphere were absent, the Sun's radiation could not produce any detectable ionosphere on Earth, and our short-wave radio communications would greatly suffer from it. It is true that the upper layers of the terrestrial atmosphere are ionized not only by radiation but also by corpuscular fluxes and other phenomena

associated with them, which explains why the ionosphere persists even during the long polar night. But in the middle latitudes the effect of these factors is small, and the main source of ionization remains the radiation of the chromosphere.

The density of the upper layers of the corona is lower than that of the lower portion, and thus they radiate even less. At this point, however, the temperature of the corona no longer grows, but rather declines. This is explained by the fact that in the outer corona a new process comes into play, which causes cooling. Part of the protons in the outer corona attain velocities at which they are able to escape from the Sun completely. The resultant emission of fast particles is similar to evaporation; it cools the corona and prevents its temperature from rising beyond a certain limit. The particles escaping from the corona form a weak stream, or wind, which manifests itself in certain geophysical phenomena and is directly measurable by means of space rockets.

Let us now consider the formations on the surface of the Sun. A conspicuous feature on photographs are the sunspots (Figure 3). These are relatively dark, because their temperature is almost a thousand degrees lower than that of the photosphere. Their dark central core is surrounded by a less dark area, the penumbra, in which the temperature is somewhat higher than in the central umbra. The number of sunspots varies from year to year, with a recurrence period of about 11 years. This period is known as the solar-activity cycle. The spots are distributed in belts which slowly move toward the equator in the course of a cycle. The sunspots usually form groups, in which there are one or two main spots. A salient feature of the sunspots is that they display a strong magnetic field, whose intensity may reach 3 or 4 thousand oersteds.

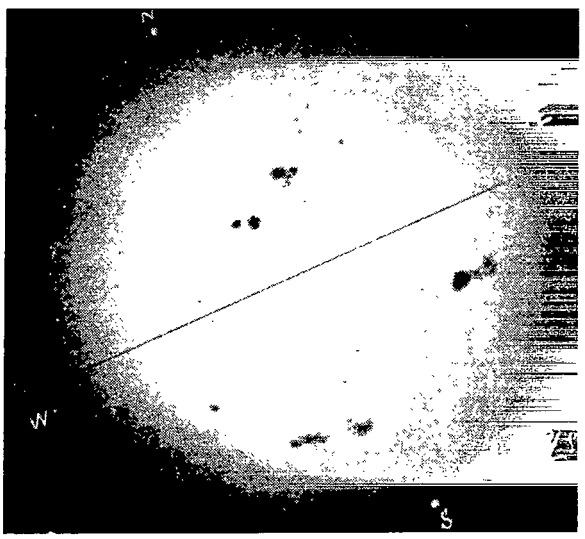


FIGURE 3

Apart from the sunspots, the Sun exhibits many other phenomena associated with the solar-activity cycle, in all of which a magnetic field is prominent, though not as strong as that of the sunspots. By means of modern instruments it is possible to detect on the Sun very weak fields, considerably weaker than the field of the Earth. Investigations have shown that there are on the Sun extensive magnetic regions, in which the field intensity goes from some fractions of an oersted to several hundred oersteds. These magnetic regions exist for several months, sometimes up to a year, and then they disappear. The magnetic field in extended masses of the conducting gas cannot actually just vanish; it only penetrates into the interior or else is carried off into space. Conversely, a magnetic region appears when the field emerges from the interior.

By analyzing the motion of the zones containing magnetic regions and the nature of the field within them it has been possible to construct a model, for the time being empirical, describing the magnetic field in the interior. In each hemisphere under the surface of the Sun there are two moving systems of magnetic force-field tubes of opposite polarity which cover the Sun along parallels. One system of tubes rises up in the middle latitudes and moves under the surface toward the equator. At the same time the other system moves in the interior, from the equator to the middle latitudes. When it approaches the equator, the first system penetrates to the interior and starts moving toward the middle latitudes, while the second system rises toward the surface and moves to the equator. An identical process takes place in the other hemisphere.

The reason for this circulation, or the mechanism generating the field, is not yet clear. The circulation has a period of 22 years, during which time two cycles of reversed polarity are completed.

Under certain conditions a tube traveling close to the surface may rise and emerge to the outside, thus forming a magnetic region. Where the intensity of the field is very high a spot is formed, and in other places an active region appears, producing a number of phenomena. The formation of the spots and active regions is caused by the effect exerted by the field on the motions in the conducting medium, and specifically on convective motions. The field inhibits motions in the medium across the force lines, if its energy is comparable with the kinetic energy of the motion. At field intensities of more than 500 oersteds the magnetic forces arrest any motion in the upper portion of the convection zone. Now since convection is the main means of heat transfer in these layers, the photosphere overlying a stagnant area receives less energy, its temperature drops, and a cool spot is formed. In regions of lower intensity the energy of the field is not sufficient to check the motion of convective currents, but it changes the pattern of motion. Under normal conditions the large-scale motion is turbulent, i.e., it is accompanied by ripples and eddies which are superimposed on the main flow. These ripples cross over from the rising current into the sinking current and thus exert a drag on the motion. This drag, known as eddy viscosity, acts on the currents rising from granules. A weak magnetic field cannot arrest the main flow, but it inhibits the ripples whose energy is considerably lower than that of the main flow. A reduction of the turbulence, and therefore of the eddy viscosity, leads to an increase in the velocity of the currents. Consequently, a weak field helps rather than hinders convection.

At the surface of the Sun, the enhanced convection results in a set of phenomena which involve all the layers of the atmosphere. In the photosphere convective heat transfer is increased, and the moving masses equalize the temperature difference between the upper and lower layers. Therefore in a region of activity the upper layers of the photosphere are hotter than in other places, and at the edge of the solar disk an active region appears as a large bright patch, known as a facula. The faster motions generate a strong flux of waves which travel from the photosphere into the chromosphere and the corona. Consequently in an active region the chromosphere heats up more, and layers of the same density have a higher temperature than they do in unperturbed regions of the Sun.

The chromosphere emits radiation in distinct lines, the intensity of emission depending on the temperature and density. In the regions of activity the emission of the principal lines is intensified, and thus if the Sun is photographed through a light filter transmitting the ultraviolet line of ionized calcium or the red H_α hydrogen line, the active regions show up as brights spots (Figures 4 and 5). These spots are known respectively as calcium and hydrogen flocculi. In the corona active regions appear as condensations, since a strong wave flux heats up to coronal temperature denser gas than does a weak flux. The magnetic field emerging from active regions into the corona imparts to the coronal formations a distinctive structure, which is visible on photographs.

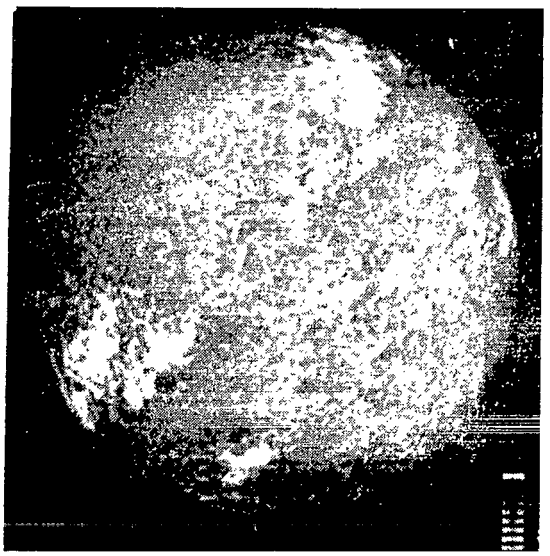


FIGURE 4

In the neighborhood of large groups of spots, chromospheric flares are sometimes observed, which are the most "active" formations on the Sun. They are most clearly seen in hydrogen spectroheliograms, where they appear as intensely bright fine details. A flare may last from several minutes

to some tens of minutes. During a flare large amounts of cosmic rays are produced, which are detectable after some time in the upper layers of the Earth's atmosphere. A high-velocity jet of gas shoots up from the flare, rising to a great height and then falling back again. This surge is apparently caused by cosmic-ray pressure. Part of the gas does not fall back to the Sun, but escapes with a velocity of more than 1000 km/sec and reaches the Earth after a day or two, where it gives rise to magnetic storms, aurorae, and other phenomena. As the stream moves through the corona it produces a burst of radio emission, whose intensity is sometimes millions of times greater than the thermal radio emission of the corona.

The appearance of flares is apparently connected with magnetic forces which strongly compress the gas under certain field configurations. On being compressed the gas heats up, and then nuclear reactions involving deuterium possibly take place, producing fast particles which are further accelerated by impinging against the moving magnetic "walls".

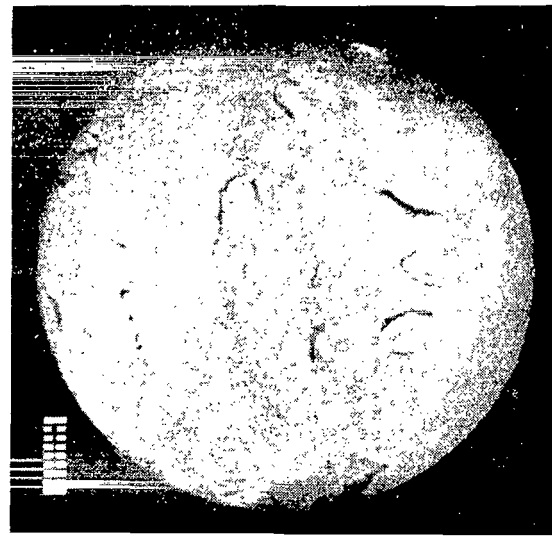


FIGURE 5

Another phenomenon associated with magnetic forces is that of solar prominences. These are relatively dense gas clouds which rise to considerable heights within the corona. They are clearly visible on the limb in H_α light, and when projected against the solar disk they show up as long dark filaments (Figure 5). They sometimes hang almost motionless, and sometimes move at a high velocity. The prominences are mostly formed in the corona. The magnetic forces compress the coronal gas to such density that it starts radiating intensely and quickly cools down. The heavy condensations are supported by the field or they slide down the inclined force lines, as may be often observed in active prominences (Figure 6).

FIGURE 6

Let us sum up. The Sun draws its energy from the nuclear reactions occurring near its center. As it diffuses upward, this energy causes motions in the gas layers closer to the surface, i.e., it is converted from thermal into mechanical energy. The motions give rise to granulation of the Sun's surface and to a wave flux heating up the chromosphere and the corona. In the presence of magnetic fields convection is suppressed if the field is strong, and intensified if the field is weak. This explains the appearance of spots and active regions. The presence of magnetic forces also explains the formation of flares and prominences. Solar phenomena have an effect on the atmosphere and the magnetic field of the Earth. The ultraviolet radiation, which is especially intense in the regions of activity, ionizes the upper layers of the terrestrial atmosphere. The X-ray emission of the flares penetrates into the deeper layers and causes fading of short radio waves for half an hour after the occurrence of a flare. The cosmic rays due to solar outbursts reach the Earth, and may be responsible to some extent for the radiation belts of fast particles surrounding the Earth. The correlation between solar and terrestrial phenomena has been subjected in the last few years to an extensive research program by scientists all over the world. This joint project was known as the International Geophysical Year and the Year of International Cooperation.

V. V. Fedynskii

SOME PROBLEMS INVOLVING BOTH THE EARTH SCIENCES AND SPACE SCIENCES

New, complex problems concerning the Earth are at present being encountered more and more often in the fields of geology, geophysics, geochemistry, and astronomy. The solution of these problems is of basic importance with respect to the development of our ideas on the structure, the origin, and the future of the cradle of mankind, our native planet.

In the present outline we wish to indicate the nature of these key problems in the Earth sciences, on the basis of some relevant examples (not necessarily the most important ones). The solution of these problems will require the collective efforts of scientists in various fields, and the results obtained will help us to develop an overall picture of our planet. The sample problems we have chosen are the following: 1) the accretion (accumulation) of meteoric matter and cosmic dust; 2) deep planetary faults in the Earth's crust; and 3) the geomagnetic field and its secular variations. Although these problems deal with very different subjects, they have the following factors in common: they are all key problems, they are all complex, and they all require a comprehensive approach and interpretation.

I. THE ACCRETION OF METEORIC MATTER AND COSMIC DUST

The interplanetary space beyond the Earth's atmosphere is by no means as empty as it was believed to be as recently as the beginning of the 20th century, when space data were still very meager. In actual fact, this space is saturated with rapidly moving high-energy elementary particles, known as cosmic rays, which come from the Sun and from distant stars and stellar systems (galaxies). Moreover, there are also a great number of larger material formations moving through the space outside the atmosphere, such as dust grains and splinters and lumps of rocky material and iron-nickel compounds. Although the density of the meteoric matter is very low in comparison with that of the closely packed matter on planets and on the Sun, still it is now clear that interplanetary space is far from empty.

During its annual journey around the Sun, the Earth sweeps up the meteoric particles that it encounters along the way. This may be compared with what happens when an automobile moving along the road

runs into a swarm of gnats and the bodies of the insects, crushed by collision with the vehicle, are deposited on the windshield. The accumulation (accretion) of meteoric matter takes place on the surface of the planet. When they strike the Earth's atmosphere at velocities of 12 to 70 km/sec (which is much higher than the speeds of artificial satellites launched from powerful rockets), the larger meteoric particles heat up, become melted, and then vaporize. As a result of this disintegration of meteoric bodies at heights of 70 to 120 km, a fine meteoric dust is produced in the atmosphere. This dust is composed of spheroidal particles with diameters ranging from several microns to a millimeter /1/. The dust settles in the Earth's atmosphere for about a month's time. In addition, the Earth's atmosphere is invaded by large numbers of tiny meteoric particles which are unaffected by interaction with the air. Because of their small mass, these particles are slowed down in the very tenuous upper layers of the atmosphere and thus are not heated up in the relatively dense meteoric zone (70-120 km) the way the more massive meteoric bodies are. This is the so-called cosmic dust.

The meteoric and cosmic dust settling onto the Earth's surface increases the mass of the planet and contributes to the material composition of the Earth's crust. At first sight, the part played by meteoric dust might seem to be negligible. However, if we take into account that the accretion of meteoric matter has been going on for at least 4 or 5 billion years, and also that the cloud of meteoric matter around the Sun during the initial stage of dust accumulation by the Earth and the other planets must have been incomparably denser, then of course the picture is different. The accumulation of the particles of a protoplanetary meteoric cloud forms the basis of Shmidt's well-known cosmogonic hypothesis /2/. It may not be possible to accept all the aspects of this hypothesis, but Shmidt's proposal that meteoric accretion played a larger part in the past seems to be quite plausible.

New factual data on the rates of accumulation of meteoric matter by the Earth have been obtained via direct studies of this matter in interplanetary space by means of artificial satellites and space rockets. Previously, comparatively large meteoric particles (a millimeter or some tenths of a millimeter in size) were studied by visual means and by radar. The total mass of meteoric matter falling onto the Earth was then estimated at a few (2 to 5) tons per day /3/. However, the picture became quite different after new direct counts of meteoric particles in space were made using instruments mounted on satellites and rockets. Soviet and American investigators have used very different techniques for recording direct encounters between the surface of a space vehicle and the meteoric grains in interplanetary space. The pits produced on plates of soft metal or polished steel by collisions with dust grains have been counted; impacts of meteoric particles have been recorded using microphones with piezoelectric crystals or photomultipliers; finally, other ingenious and diverse observation methods have been used. The counts of the number of collisions were then telemetered back to Earth or else studied upon recovery of the satellite or rocket. In this way, we have been able to obtain information on grains of meteoric matter 4 or 5 microns in diameter with masses as low as one billionth of a gram [10^{-9} gram]. Such measurements are feasible both because of the extremely sensitive instruments used and because of the enormous energies of collisions with meteoric particles, the average collision velocity being about 40 km/sec.

In addition, during recent years the techniques for collecting meteoric and cosmic dust in the Earth's atmosphere have been refined considerably. Samples of this dust have been taken using jet aircraft flying at altitudes of 7 to 16 km, and they have also been obtained from the snow covers of glaciers in high mountains and in the Antarctic.

Consequently, the growth of the Earth as a result of the accretion of meteoric matter is now estimated as being from 13,000 to 80,000 tons daily, which gives a yearly average growth of about ten million tons! We might ask ourselves at this point why the discrepancy with the previous estimates is so great. The answer is obviously that the quantity of very fine meteoric dust in interplanetary space was previously underestimated. For example, it was assumed that the quantity of meteoric particles increases in inverse proportion to the mass of the individual particles, so that the total mass of particles of any given size remains constant. In reality, the total mass of meteoric matter increases with a decrease in the mass and size of the individual particles, as has been verified by recent, more careful, comparisons of the results of visual, radar, and rocket observations for a number of meteors.

An amount of meteoric accretion to the tune of 10 million tons (10^{13} grams) yearly certainly should be taken into account with respect to the life of our planet, the more so since (as we noted above) this factor was even more effective during previous stages in the evolution of the Earth. Even though the mass of the accumulated meteoric matter (10^{13} grams) is infinitesimal in comparison with the total mass of the Earth ($6 \cdot 10^{27}$ grams), it is nevertheless significant in comparison with the mass of the Earth's crust. Deep seismic soundings have made it clear that the mean thickness of the Earth's crust is 40 km on the continents and 6 km in the oceans. If the density of the crust is taken as 2.8 g/cm^3, and if the percentage of the Earth's surface occupied by the continents and oceans is taken as 29 and 71 % respectively, then the total mass of the Earth's crust is about $2 \cdot 10^{25}$ grams. Thus, even if the accretion rates throughout the geological past had been as insignificant as they are at present, the total amount of meteoric matter deposited on the Earth during the 4 billion years of its existence would still amount to $4 \cdot 10^{22}$ grams, or 1/500 of the present mass of the crust. However, this is only a lower limit for the "cosmic" contribution to the composition of the outer crust of the Earth. In reality, this contribution was considerably larger. Meteoric accretion played a very important part in the formation of deep-water deposits in the open sea, where other deposit-producing factors are less effective than they are at other places on the Earth's surface. Iron globules containing admixtures of nickel, which have been found in core samples of deep-water deposits, attest to the fact that meteoric matter has been falling onto the Earth at least throughout the entire Tertiary period.

It should be noted at this point that the accumulation of cosmic matter on the Earth, the significance of which has been established by the studies of recent years, is accompanied by the opposite process of the escape of terrestrial matter into space.

Gas molecules and atoms continually leave the Earth's atmosphere, provided that their velocities exceed, for some reason or other, the "escape velocity". The latter is the critical velocity required for a body to extract itself from the sphere of terrestrial gravity. An even greater

amount of matter is ejected into space as a result of volcanic eruptions, and also during the explosions caused when the Earth collides with gigantic meteorites. Moreover, the artificial explosions which have taken place since man discovered atomic energy also have been on a cosmic scale. Geologists are unanimous in the opinion that, during past epochs in the history of the Earth, volcanic activity was even more intense than it is at present. As yet it is impossible to evaluate the loss of matter by the Earth quantitatively, and it is not even known which exchange process predominates, the accumulation of matter on the Earth or the escape of it from the Earth.

One thing is certain: an exchange of matter continually takes place between the Earth and space, and the scale of this exchange is such that it must be taken into account when considering the present state and the past history of the Earth. In the past this exchange was much more intensive, so that the struggle between the two opposing factors must have been more pronounced than it is now. The present example thus confirms the correctness of the remarkable ideas held by the prominent natural scientists Vernadskii and Fersman, the founders of Soviet geochemistry. The Earth and space were considered by Vernadskii (1863-1945) to be regions of transient physicochemical equilibrium, between which a continuous exchange of chemical elements takes place /4/. In his book "Geochemistry", Fersman (1883-1945) stressed the idea of the exchange of matter when he wrote: "... in general the force of dispersal and the force of attraction, ... mutually compensating one another, equalize the chemical composition of the universe. There is no basis for assuming that a chemical equilibrium exists and that the present distribution of elements in space is stationary. On the contrary, everything goes to show that the chemical elements are shifted and regrouped according to definite laws, first combining into chemical compounds and then decomposing again" /5, p. 217/.

Launchings of artificial satellites and space rockets have shed new light upon the problem of the exchange of matter between the Earth and space. They have provided the physical basis for a more profound treatment of this problem, which involves astronomy, geology, geochemistry, astronautics, and other fields as well.

II. DEEP PLANETARY FAULTS IN THE EARTH'S CRUST

Many books and articles have been written about the structure of the Earth's crust, but it is only recently that geophysical observations have made it possible to specify the basic subsurface features of this structure. The Earth's crust, which has a thickness varying from 5 to 75 km, is characterized by physical parameters which are quite different from those of the underlying intermediate layer, the outer parts of which are known as the upper mantle. An intensive exchange of matter and energy takes place between the mantle and the overlying Earth's crust, and the mantle constitutes a source of the movements and development of the crust. Different portions of the crust react in different ways to the influence of the upper mantle, and as a result the Earth's crust is now

made up of large blocks, differing from one another in structure and divided from one another by deep faults. Each of these blocks has its own characteristic depth cross section, with some combination of basaltic, granitic, and sedimentary layers. Moreover, each block has its own characteristic geological system of surface layers, its own particular type of geological structural forms, and its own evolutionary history. A block is usually framed by deep faults in the crust, and is often even cut up by such breaks and faults.

Some typical indications of deep faults are: 1) a pronounced difference between the deep structure of the crust on the two sides of a fault; 2) intensive uplift of the heavy, deep magmas along faults; 3) the appearance of sharp gravitational and geomagnetic anomalies over faults; and 4) the formation of rich, sizable mineral deposits in the fault zones. It is interesting that, according to all these criteria, a formation in the Earth's crust such as the Urals should be considered as a deep fault. The Precambrian Russian Platform extends to the west of the Urals, and as early as the first part of the Paleozoic era sedimentary layers were gently deposited on it. To the east of the Urals, however, the intensive impregnation of the Earth's crust with deep magma only stopped prior to the Jurassic period, at which time the rigid Paleozoic fundament was able to become consolidated. In the Urals the deep greenstones rose up to the Earth's surface, and heavy-dunite massifs of basic composition were formed. The Urals are characterized by marked gravitational and magnetic anomalies. And finally, in the depths of the Urals, innumerable, really fabulous, resources of precious stones were stored up.

The Urals represent a deep fault of ancient origin. There are, however, some deep faults in the world which are more recent. Let us consider the transition zone from the Pacific Ocean to the Asian continent, which was recently studied by Soviet scientists during the International Geophysical Year (1957-1958) /6/. The deep fault in the planet's surface located in this zone is known as the Kuril Island Arc. West of this arc the Earth's crust has an overall thickness of 30 to 35 km and is definitely of the continental type, while to the east it narrows down to 5 to 8 km and is oceanic. Even at present, along the Kuril-Kamchatka volcanic line products of deep-magma differentiation are brought up to the surface, and the depths of the region are shaken by powerful seismic jolts. The Kuril-Kamchatka tectonic line on the Earth's surface is associated with strong anomalies of gravity and of the magnetic field.

Another deep fault, part of which extends under the ocean, was studied by the Dutch geophysicist Vening Meinesz /7/. This fault is the Indonesian island arc, together with its submarine framework. The Soviet geophysicist Lyustikh has shown very graphically that those oceanic zones which were described by Vening Meinesz as downfoldings of the crust are actually junctions between two different types of crustal blocks /8/. Vening Meinesz, Kuenen, and other investigators after them suspected that in the submarine region of the Indonesian arc we are dealing with the rudiments of a mountain chain on the Earth's crust, and the more explicit treatment of Lyustikh serves to bolster this idea.

The Urals, washed out by secular erosion, the highly uplifted mountain summits of Kamchatka, the Kurils, and Japan, and finally the tectonic line hidden beneath the waters of the Indian Ocean, represent three stages

in the evolution of large mountainous structures on the Earth's crust. It is characteristic of deep faults in the Earth's crust that they form segments or systems of segments of small circles on the Earth's surface; from the geometrical point of view, these circles represent traces on a sphere along which the latter is intersected by surfaces. Thus, considered from outside, planetary deep faults appear to be regular geometric lines on the surface of the spherical Earth. This fact is evident from any careful study of a globe of the Earth.

During the present period, which is a period of jet aviation and space flights, planetary faults in the crust can be observed clearly in nature as well as on a globe of the Earth. The faults show up as regular geometric contours on the Earth's surface. When a jet aircraft at an altitude of 11 or 12 km passes the "roof of the world" (the Pamir highlands) and goes out into the aerial spaciousness over the Indian plain, it is clear to any geologist or geophysicist aboard that the Himalayas, the highest mountains in the world, also crown the boundary between two blocks of the Earth's crust: the high-mountain block of the Pamirs and Tibet, and the crystal massif of the Deccan. Like a wall, the Pamir-Tibetan highlands form a steep vertical barrier, and individual peaks, produced by intensive erosion of the high mountains, stand out upon the uplifting of the Earth's crust in this region. One of these peaks is the highest mountain on the Earth, Chomolungma [Mt. Everest].

Deep faults in the Earth's crust, which are an important characteristic of the crustal structure, are a consequence of the active internal life of our planet. Now let us see whether analogous faults exist on any of the other celestial bodies. We have only to consider carefully the surface of the Moon, in order to recognize upon it formations which are very reminiscent of the deep faults in the Earth's crust. The steep side of the lunar Apennines which overhangs the flat, rather dark, surface of the Mare Imbrium reminds one immediately of the terrestrial Himalayas rising above the Indian plain. An intersection between the spherical surface of the Moon and a sharply incident surface lying along the arc of a small circle, exactly as in the case of the island arcs of the Earth, is observed along the line of the lunar Apennines and the other mountain chains of our satellite.

Consequently, deep planetary faults, together with their characteristic morphological features, apparently exist both on the Earth and on the Moon, and, in all probability, on the other terrestrial planets (Mercury, Venus, and Mars) as well. It is not impossible that on the strongly eroded surface of Mars the traces of deep planetary faults are observed by us in the form of the very puzzling "canals" of Mars, concerning the nature of which so many hypotheses have been made. Were we to observe from outer space the geometrically regular island arcs and mountain chains of our planet, or just the boundaries between two blocks of the Earth's crust, we might also be led to postulate an artificial origin for such quite natural planetary formations as deep faults.

It was noted at the beginning of this section that deep faults in the crust are regions where mineral deposits are formed. Thus the study of these faults is of great practical value as well as being of theoretical interest. At present scientists are gradually exploring the possibility of investigating deep faults by comparative methods (by studying planetary cracks on the surfaces of other bodies in the solar system), in addition to penetrating

into the Earth's interior by geophysical and geological means, which has always been (and still is) the chief method of studying the faults. Geologists, geophysicists, astrophysicists, and astronauts are thus all confronted by a common problem of greater complexity, the solution of which requires the combined efforts of representatives of all fields.

III. THE MAGNETIC FIELD AND EXOSPHERE OF THE EARTH

The examples cited would very likely suffice to illustrate the relations which are now being found between the Earth sciences and the sciences describing the universe surrounding the Earth. These relations between the sciences became established as we began to use our increased opportunities for the study of outer space to solve individual important problems. We wish to present an additional example, however, one which will show particularly clearly that this convergence of the interests of the different sciences simply represents objectively the natural relations which exist between the Earth and the space surrounding it.

Long ago navigators learned to guide their vessels according to a compass, the magnetic needle of which undeviatingly indicates the direction of the meridian. Moreover, it has been known for a long time that the Earth is a magnetized sphere and that the position of the magnetic pole is only slightly different from the position of the geographic pole. It was discovered just recently, however, that the Sun and the stars also possess magnetic fields, and that the stellar, solar, and geomagnetic fields vary continuously. Since paleomagnetism and its geological aspects were recently examined in an article by Kropotkin /9/, it will not be necessary to discuss the subject in any detail here. Let us just recall the following two well-established facts: 1) the polarity of the geomagnetic field changes approximately once during a period of several tens of thousands of years; 2) the magnetic poles drift over the surface of the Earth with the passage of geological time /10/. The second of these facts is related to the shifting of the Earth's crust relative to the rotation axis and does not have any significant effects in the space around the Earth. The reversal of the polarity of the geomagnetic field, however, and the disappearance of the field at the time when the field strength passes through zero, bring about considerable changes in the exosphere of the Earth, as the very distant portion of the terrestrial gaseous envelope is now called.

Studies made using artificial satellites and space rockets have shown that the atmosphere of our planet actually extends far out into space. In 1950 the Soviet astronomer Astapovich noted the presence of a gaseous tail near the Earth, oriented in a direction away from the Sun, and he estimated its extension as being several thousand kilometers. Then, in 1958, on the basis of satellite and rocket observations of cosmic rays, the Soviet physicist Vernov and the American scientist Van Allen discovered an intense radiation belt around the Earth, located at an altitude of about 2000 or 3000 km /11/. This belt is saturated with high-energy elementary particles. These charged nuclear particles, which are ejected by the Sun and the stars, fall into magnetic traps associated with the geomagnetic field. A cloud of very fine meteoric bodies is apparently picked up by

these magnetic traps around the Earth as well, the electrical charges on the surfaces of the particles being important for such small particle masses (see § 1 of this article).

Thus, the radiation belts, and very likely the cloud of cosmic dust around the Earth as well, owe their presence to the extent to which the geomagnetic field can hold their constituent particles in the traps created by it. As the polarity of the geomagnetic field goes through its gradual cycle of reversals, the magnetic traps of the Earth must become sometimes stronger and sometimes weaker, and they will disappear periodically for short periods of time (perhaps for some decades or centuries). The disappearance of the magnetic traps, even for a short time, destroys the radiation belts and the meteoric cloud around the Earth during this period. Such a pulsation of the exosphere, and the periodically recurring disappearance of its basic elements, cannot take place without having some effect on the interaction between the Earth and other bodies in space. It is difficult to say at present just what effect these variations have on processes taking place in the Earth's atmosphere, but still it is possible to speculate on the nature of this effect. Most likely, when the barrier impeding the arrival of cosmic rays disappears, the ionization of the upper layers of the atmosphere will increase. At the same time, the reduction of the density of cosmic dust around the Earth will lead to a reduction of the absorption of solar radiation in interplanetary space. Atmospheric processes which are induced by ionization of the upper atmospheric layers will be intensified. For example, under these circumstances there will be a more intensive circulation of matter in the atmosphere, and climatic processes will become more pronounced. It is possible, therefore, that some long-period climatic variations depend on the variations in the geomagnetic field. These climatic changes must affect the entire Earth simultaneously, and in the past they must have greatly influenced animal and plant life on our planet.

In our brief account of the interdependence of terrestrial and space phenomena associated with the geomagnetic field, we began with the compass and ended with the possibility of climatic and biological variations which are effected simultaneously with variations in the Earth's magnetic field. However, many scientists now believe that the source of the geomagnetic field and its variations is the Earth's core, with its system of ring currents. Consequently, variations taking place within the very depths of the Earth are able to bring about changes in the distant exosphere of our planet and thereby to influence conditions on the Earth's surface.

The purpose of this article has been twofold. First of all, we have tried to emphasize that the individual Earth sciences and space sciences (such as geology, geophysics, geochemistry, astrophysics, and cosmogony) are now making more and more contact with one another. Secondly, we have tried to show that this trend toward a greater complexity and interrelation of fields which were previously relatively separate is a result of certain basic connections existing in nature, the recognition of which has now become imperative for modern science. If the reader has become aware of this through the examples presented in this article, then our goal has been achieved.

REFERENCES

1. KRINOV, E. L. Osnovy meteoritiki (The Fundamentals of Meteoritics).— Moskva, Gostekhizdat. 1955.
2. SHMIDT, O. Yu. Chetyre lektsii o proiskhozhdenii Solnechnoi sistemy (Four Lectures on the Origin of the Solar System). — Moskva, Izdatel'stvo AN SSSR. 1950.
3. WATSON, F. G. Between the Planets. — The Blakiston Co., Philadelphia. 1941. [Russian translation. 1947.]
4. VERNADSKII, V. I. Ocherki geokhimii (Outlines of Geochemistry), 4th Edition. — Moskva-Leningrad, Gosizdat. 1934.
5. FERSMAN, A. E. Geokhimiya (Geochemistry), Vol. I. — Leningrad, Goskhimtekhizdat. 1933.
6. GAL'PERIN, E. I., S. M. ZVEREV, I. P. KOSMINSKAYA, et al. Issledovaniya zemnoi kory v oblastyakh perekhoda ot aziatskogo kontinenta k Tikhomu okeanu. Raboty Tikhookeanskoi kompleksnoi geologo-geofizicheskoi ekspeditsii AN SSSR v 1957 g. (Studies of the Earth's Crust in Regions of Transition from the Asian Continent to the Pacific Ocean. Works of the Combined Geological-Geophysical Pacific-Ocean Expedition of the USSR Academy of Sciences in 1957).— Moskva, Izdatel'stvo AN SSSR. 1958.
7. VENING-MEINESZ, F. A. Gravity Expeditions at Sea. — Netherlands Geodetic Comm. 1934. [Russian translation. 1940.]
8. LYUSTIKH, E. N. Anomalii sily tyazhesti i glubinnaya tektonika Indonezii i drugikh ostrovnykh dug (Gravity Anomalies and the Deep Structure of Indonesia and Other Island Arcs). — Trudy Geofizicheskogo instituta AN SSSR, No. 26, 156. 1955.
9. KROPOTKIN, P. N. Paleomagnetizm i ego znachenie dlya stratigrafii i tektoniki. Doklad na sessii otd. geologo-geogr. nauk AN SSSR 8 iyunya 1960 g. (Paleomagnetism and Its Significance in Stratigraphy and Tectonics. Report at a Session of the Division of Geological and Geographical Sciences of the USSR Academy of Sciences on 8 June 1960). — Izvestiya AN SSSR, seriya geologicheskaya, No. 12. 1960.
10. KHRAMOV, A. N., G. N. PETROVA, A. G. KOMAROV, and V. V. KOCHEGURA. Metodika paleomagnitnykh issledovanii (Methods of Paleomagnetic Research). — Leningrad, Gostoptekhizdat. 1961.
11. VERNOV, S. N., A. B. CHUDAKOV, et al. Issledovanie izluchenii v kosmicheskom prostranstve. Sm. kn. "Radiatsionnye poyasy Zemli. Pervichnoe kosmicheskoe izluchenie, ego svoistva i proiskhozhdenie" (The Study of Radiations in Outer Space. Cf. the book "The Radiation Belts of the Earth. Primary Cosmic Radiation, Its Properties and Origin"). — Moskva, Izdatel'stvo AN SSSR. 1961.

PART THREE
STRUCTURE AND EVOLUTION OF THE EARTH

B.L. Lichkov

SYMMETRY FEATURES OF THE EARTH ASSOCIATED WITH THE GRAVITATIONAL FIELD, STRUCTURAL GEOLOGY, AND HYDROGEOLOGY

(Interaction of the Terrestrial Envelopes. Regularities of the Motions in the Envelopes)

In my recent book entitled "The Natural Water of the Earth and the Lithosphere" (1960), I formulated a new theory of orogenesis. According to this theory, orogenesis is part of a process of re-formation of the planetary figure of the Earth related to variations in the velocity of terrestrial rotation, which cause an increase or a decrease in the planetary or polar flattening of our planet. I called this re-formation of the Earth's figure spreading of the Earth.

According to Shmidt's theory, spreading first took place during the period in which the spheroidal body of the Earth formed from an angular asteroid. The spreading which occurred at this time, during the increase in the dimensions of the asteroid and as a result of this increase, was the biggest spreading in the history of the planet. It may be assumed to have taken place when the Earth changed from a region of cohesive forces into a region of attractive (gravitational) forces. Spreadings recurred during each new orogenetic process.

Such orogenesis, then, is the part of the re-formation of the figure of the planet which occurred in the solid envelopes of the Earth, and which manifested itself most distinctly in the lithosphere. It is this part of the re-formation of the figure which we have called the spreading of the solid body of the Earth. The spreading takes the form of large-scale subcrustal tangential displacements of mass at the poles, at the 62nd parallels, and at the equator. Such displacements do not take place at the 35th parallels.

As a consequence of the tangential mass displacements over large distances, upheavals and subsidences of the topography take place at the 35th and 62nd parallels, that is, at the two definite boundaries of the zones, and also at four definite antipodal meridians located 90° from one another. This situation may be assumed to result from the existence of critical parallels and critical meridians which develop during rotation of the planet and which determine the structure of the Earth. The shape of the Earth, therefore, is not something which was handed down to it from a previous liquid phase (as was assumed, for instance, by Clairaut). Rather, it is an acquired characteristic which can be attributed to the loss by the planet of the angular form possessed by the asteroid.

The empirically observable distribution of mountain chains over the

terrestrial ellipsoid can be substantiated mathematically. Stress-discharge zones must have appeared in the crustal layer, which also explains the existing distribution of mountain ridges. The most deformed zones should be: the equator, the critical parallels at ±35° and ±62°, and the poles, as the studies of Stovas over the last ten years have demonstrated. The maximum stress and maximum shifting of areas is at the 62nd parallel and at the equator, and minimum shifting takes place at the poles and at the 35th parallels.

The equator and the 62nd parallel are conjugate parallels. By this we mean that an increase in the length of one of these results in a decrease in the length of the other. The length of the 35th parallel, however, remains constant for a change in the degree of flattening. The conjugate variation of the length of arc of the equator and the 62nd parallels should cause deformations (tangential latitudinal stresses) there. These stresses are a maximum at the equator and they decrease with the approach to the 35th parallel, where they drop to zero. Further on, according to Stovas, the sign of the stress is reversed. It continues to increase toward the high latitudes, reaches a maximum at the 62nd parallel, and then decreases toward the pole, where it is once again zero. In general, as Stovas points out, a meridional warping of the surface of the Earth's figure should be produced. The meridional tangential stresses cause latitudinal deformations.

This relationship between the parallels must be taken into account for all the envelopes of the Earth, and not just for the lithosphere. In other words, each of the terrestrial envelopes, solid, liquid, and gaseous, represents a definite structure (or rather a complex combination of several structures), produced under the conditions of terrestrial rotation and existing as a direct result of this rotation. Under the rotation conditions, in accordance with the effect of gravity, both the atmosphere and the hydrosphere, like the lithosphere, prove to be definite megastructures; they have a complex structural makeup, rather than being just air and water*.

Actually, this follows from the last chapters of my aforementioned book, in which it was noted that the same critical parallels exist in the atmosphere and hydrosphere as on the solid surface of the Earth corresponding to the lithosphere. The meridional zonal slanting , whose existence for the solid envelope of the Earth was pointed out by Stovas, must also be observed for the air envelope and the water envelope of the Earth. Under the conditions of terrestrial rotation, water cannot travel freely from the pole to the equator and vice versa. Along the way, the water will be affected by the 35th parallel and in fact will be stopped at it. Up to the 35th parallel it will have one kind of motion, and after this parallel it will have another kind. It is no accident that the maximum water density in the oceans is along the 35th parallel. Nor is it an accident that regions of constant wind ("the roaring latitudes") exist in the atmosphere on either side of the 35th parallel.

Obviously, a definite figure of the Earth applies to the solid envelope of the planet as well as to the oceans. Moreover, the figure would be the same if there were no oceans, since then the dry land itself would compensate for the lack of the water and the oceanless Earth would still be ellipsoidal in shape. Since the oceans do exist, however, they are an

* [The author later refers to this as the first-order regularity.]

inherent constituent part of the Earth's structure, and this is why the oceans complement the continents so exactly in the body of the Earth (and thus in the structure of the planet as well). On the basis of this, we may conclude that, in particular, the troposphere (the lower part of the atmosphere) must have a definite planetary figure. The troposphere contains a subtropical high-pressure zone, an equatorial region of low pressure, and finally the polar zones and anticyclone zones of the Arctic and Antarctic. Each of these tropospheric zones has an analogue in the lithosphere.

Let us assume that each envelope of the Earth, solid, liquid, or gaseous, consists of masses of matter which are present in the different envelopes in different states. Then, invoking the previous important first-order regularity which states that the envelopes are made up of structures, we are justified in saying that: these structures are masses of matter in different states. Zonality of the structures is, therefore, a phenomenon which is inherent to the masses making up the envelope. If this is taken into account, it follows that the available heat must also exert an influence on the masses of the envelopes, apart from and in addition to (but only in addition to!) the rotation. This heat may be radioactive heat in the body of the planet and also heat transmitted to the planet by the Sun through the planetary rock mass (during subsidence of the silicates and carbonaceous rocks). It is very characteristic that the masses of the troposphere and the oceanic envelope have a definite structure, as do the masses of the solid lithosphere, and this fact must be taken into consideration.

Not long ago (1956) Pariiskii contradicted Stovas by pointing out that it is impossible to assume a single rule of critical parallels for the solid Earth and the Sun, since matter on the Sun is in a fluid state. On the other hand, if the atmosphere and hydrosphere of the Earth are not simply large masses, but rather are law-abiding gaseous and liquid parts of structures, then the fluid matter on the Sun, with its regular latitudinal belts, must have a definite structure as well. Thus, there is a definite rule of latitudinal zonality which applies to all the heavenly bodies, planets and stars alike.

All three outer envelopes of the Earth, atmosphere, lithosphere, and hydrosphere, have the same pattern of latitudinal zonality. This second-order regularity follows from the previously stated first-order regularity. It becomes obvious if we assume that the basic condition for the conformity of all three envelopes is the rotation of the Earth, a certain additional role being played by heat.

Consequently, if the rotation of the planet leads to a common zonality of the envelopes, we can conclude that: the climatic and tectonic life of the planet is subject to this same latitudinal zonality. This third-order regularity is implied by the first two.

The third regularity can be explained only in terms of an interaction between the terrestrial envelopes, under conditions where the masses of each envelope move at their own particular velocities, so that motions of different phase appear along the rotation axis of the Earth (that is, perpendicular to the latitudes). It is obvious that, if the velocities of motion of the envelopes are different, the atmosphere and hydrosphere will affect them. Certain conclusions can be

drawn from this. The evolution of the Earth's solid crust can be explained most simply on the basis of the law of gravity, by assuming it to be a consequence of this law under the given conditions of planetary rotation, and orogenesis can be explained in the same way. Moreover, this same law of gravity and motion of the gravitating masses explains the motion of the atmosphere.

It is not possible, on the other hand, to explain the motion of the atmosphere purely in terms of the thermal conditions. Similarly, thermal conditions cannot account for the structure of the Earth (although hitherto it has been almost universally accepted that they could). However, both these phenomena can be explained by the combined effects of the rotation of the Earth and gravity. Phenomena originating in the atmosphere can be accounted for more by the structure of the atmosphere itself than by the radiant energy of the Sun and its influx; in any case, this atmospheric structure must not be ignored.

How deeply into the Earth does this common zonality of the body of the planet extend? Apparently very deeply indeed, since it applies not only to the [outer] lithosphere but also to the barysphere [centrosphere] and the mantle as well.

Earthquakes and seismic surveying tell us a great many things about the interior of the Earth. As pointed out by Morain (1927), the latitudinal distribution of earthquakes indicates an increase in seismicity at the 35th parallel and at the equator. According to Lichkov (1929), the zonality of earthquakes is associated with the rotation of the Earth and thus correlates well with the zonality of epeirogenic movements. This also pertains to the most ordinary shallow earthquakes with hypocenters at depths of around 30 km.

Stoyko (1952) states that deep-focus earthquakes with hypocenters at depths greater than 70 km show their relation to the Earth's rotation most clearly. He confirmed the special seismicity of the regions around the 35th parallel and the equator, and he found a definite correlation between deep-focus earthquakes and fluctuations in the angular velocity of the Earth's rotation. Stoyko explained this correlation in terms of the special state of the interior of the Earth in these regions, and he assumed that the frequent earthquakes appearing as a consequence of this special state indicate a variation in the velocity of terrestrial rotation.

However, it may be more logical to take the point of view stated by us previously, according to which in this case we have to do with something other than a special critical state of the material of the Earth which causes changes in the volume of this material. As Eigenson (1954) has pointed out, the variation in rotational velocity is apparently a result of the action of external repulsive forces. Seismic phenomena, according to this interpretation, are a unique means of relieving the excess stresses which we referred to above when discussing the regions of the subcrustal layer. Deep faults in the Earth's crust are confined to the 35th parallel, and consequently the genesis of these planetary faults is related to the rotation of the Earth (Sel'skii, 1949).

It is quite clear that deep-focus earthquakes in the Tethys region and in its continuation into Asia are confined to focus depths of the order of 300 km. Obviously, in this case the effect of the Earth's rotation will reach to this depth, producing latitudinal structures. In Europe the results of this effect show up down to depths of no more than 100 to 120 km. Faults are in all probability related to deep-focus earthquakes.

All the foregoing is characteristic of the common latitudinal zonality of the body of the Earth. This zonality, moreover, applies to the depths of the planet, including the mantle, as well as to the surface regions. Finally, it also holds true in all of the circulating envelopes of the Earth, both gaseous and liquid. Thus, like the solid body of the Earth, the liquid and gaseous envelopes around it are also closely related to the structure of the Earth, which on the whole is determined by the terrestrial field. In other words, the establishment of critical parallels is important for the reorganization of meteorology as well as of geology. If explanations of transformation phenomena in terms of thermal causes are unsuitable in geology, then, as Usmanov has pointed out, they will be equally unsuitable in meteorology.

New opinions on these subjects were developed in meteorology considerably earlier than in geology. The first to express views on them was Voeikov, who in 1882 noted the existence of two main parallels in the atmosphere. It was only later that Tillo referred to a critical 35th parallel for the lithosphere and demonstrated its existence. At present Usmanov is continuing to develop the assumptions of Voeikov and his successors, one of whom was Brounov (1924).

In addition, we should definitely add the following. Stovas is quite correct when he says that mountain chains are for the most part located along the critical parallels. However, he analyzes only the processes taking place in the lithosphere, whereas all the envelopes of the Earth play a part in producing disturbances, the activity of the envelope apparently decreasing from the troposphere down to the Earth's core. Therefore, the theory of Stovas will be incomplete if the roles of all the mutually interacting envelopes are not taken into account. This will be especially true if the atmosphere and hydrosphere are not considered, and probably the ionosphere and mantle of the Earth as well. All these envelopes have a structural makeup as well, and their active participation in the production of disturbances must by no means be underestimated.

Consequently, on the basis of the aforementioned regularities of first, second, and third order, we can now formulate a fourth-order regularity. According to the new regularity: dislocations and deformations of the Earth originate in the interaction of the out-of-phase motions of all the terrestrial envelopes, these motions being produced by the rotation of the masses of these envelopes, heat (primarily solar heat) being at the same time transferred to the envelopes.

I have especially reviewed all the studies of Stovas in order to ascertain definitely whether he refers to processes taking place in the hydrosphere and atmosphere, and I have become convinced that there are almost no such references in his works. I was the first to indicate to Stovas the part played by Tillo in discovering the [critical] 35th parallel, and I also pointed out Voeikov's discovery of the critical parallels in the atmosphere in 1882. Later he himself showed me the aforementioned work of Brounov (1924), in which the existence of [critical] parallels in the atmosphere is also indicated.

However, nowhere in his works does Stovas refer to critical parallels in the atmosphere. It was only in 1960, in a short note in "The Theory of Critical Parallels" (1960), that Stovas mentioned in passing the ideas

expressed by Khromov, Usmanov, Trauberg, and others concerning critical parallels "in the general circulation of the atmosphere". On the basis of this I wish to point out that, in spite of the very great significance of his assumptions for the theory of the Earth, and in spite of his attempts to enlarge the problem of the formation of deformations and dislocations of the Earth's crust on the basis of the interaction of the envelopes, still Stovas has provided only a starting point for the solution of this problem. The first to refer to the interaction of the envelopes as a source of tectonic phenomena was Lichkov (1960).

In one of his recent works (1960) Stovas introduced into his theory, to no purpose at all, the idea of gigantic continents. In this work (see Figure 3 on page 59) he refers to Gondwanaland, Laurentia, etc., continents which probably never existed. Such ideas only spoil his otherwise quite correct, simple, and excellent analysis. Large continents are completely unnecessary to his theory. Moreover, Stovas understood very well that, regardless of the physical state of the mass of the envelope, the regularities of the behavior of zonal structures under the conditions of rotation of an ellipsoid with polar flattening, will be the same for any form of matter.

So far we have said nothing about submeridional dislocations, a type which includes, in particular, the dislocations bordering upon the Pacific Ocean, which play a leading role. The distribution of these dislocations was described in my recent book (1960). In the Northern Hemisphere such dislocations are distributed symmetrically over the body of the planet, at 90° intervals; they include the Cordilleran Ranges, the Mid-Atlantic the Ural-African Graben, and the Kuril-Japanese Range.

As I see it, in the Southern Hemisphere this antipodal character of the critical meridians is disturbed somewhat, since the distribution of the continents (in relation to their antipodal character relative to the ocean) is different; here the distribution is somewhat otherwise than in the north. Katterfel'd and Spitaler think that even here there is a symmetrical distribution of the dislocations along the meridians. According to Spitaler, the four meridians to which the mountainous belts are confined are the critical meridians. Like the critical parallels, they characterize the symmetry of the Earth, and their properties are determined by a distribution of stress zones which is nearly latitudinal. Obviously, if the critical parallels are associated with meridional stresses, in the present case we have to do with the effect of latitudinal stresses. The direction of these stresses, however, has been studied even less, and much remains to be done with respect to studying them.

The critical meridians and parallels are significant for the water and air envelopes of the Earth as well as for the solid body of the planet. Their importance with respect to the water envelope has been recognized for a long time. The Pacific dislocations are obviously confined to the boundary between the continent and the ocean; they are displaced somewhat from the actual boundary, but they are strictly parallel to it. It is clear that these dislocations are closely related to those of the belt nearer the surface, as their parallelism indicates. In this case the role of the interaction of all the envelopes is perhaps even more obvious than for the latitudinal dislocations. This is not as clear for the Ural-African dislocation and for the Mid-Atlantic Ridge, and they still require further study. However, their origin was apparently of the same type. It may be that

the vagueness of the picture for these large dislocations is explained by the fact that they are of secondary importance, since they are only the gravimetric antipodes of the main dislocations playing an active role in this case.

In connection with the Pacific earthquake belt, corresponding to the regions of the Pacific deformations, I should like to note that they reach depths of more than 700 km, that is, they correspond to the deepest deformations (in particular, to deformations which are deeper than the deepest ones in the Tethys-Indian Ocean region). These earthquakes, and the deep faults in the Earth's crust associated with them, have the same distribution as the smaller earthquakes do (their lines are parallel to one another). Both are oriented along critical meridians, and this is also noticeable in the Asian-Australian belt of the Pacific. This fact is noteworthy, since these same features characterize the symmetry of the body of the Earth, once we assume critical meridians as well as critical parallels. It should be emphasized that the meridional symmetry extends even further into the depths of the Earth than the latitudinal symmetry does. However, this still must be verified by more thorough investigations. For us here it is significant that, in the terrestrial gravitational field, the Earth's symmetry is expressed both in its gaseous and liquid outer envelopes and in the interior of the planet, down to the core itself.

We have mentioned that the theory of critical parallels proposed by Stovas makes no reference to the interaction of the envelopes or to the role of this interaction in carrying the effects of tectonic phenomena to great depths. The same applies to the theory of critical meridians of Katterfel'd and Spitaler, since they also ignore both the interaction of the envelopes and the interaction between oceanic tides and the continents.

The theory that the waters of the ocean exert a tidal effect on the continents was introduced by W. Thomson [Lord Kelvin] and formulated between 1879 and 1890 by G. H. Darwin. A good statement of the theory is given by Ball (1909). The basic idea of this theory was expressed correctly by Engels in "The Dialectics of Nature", when he stated that in the tides the Earth-Moon system transfers energy to individual regions on the Earth's surface. However, since the theory of critical parallels and meridians was still unknown in their time, the three above-mentioned investigators had no possibility of accurately specifying the regularities of distribution of the regions that Engels referred to. Now it is quite possible to do this, on the other hand, since a theory of critical parallels and meridians exists. The latter theory makes it possible to go even further, provided we complement it and the theory of a tidal effect of the ocean upon the continents with a clearly formulated conception of the interaction of the terrestrial envelopes which go to make up the body of the Earth, from the surface regions of the planet to very great depths. This is precisely what we are arriving at in the present article. By virtue of the interaction of the envelopes, then, spreading of the body of the planet originates.

The foregoing leads us to some general conclusions concerning deformations of the Earth's crust in the two main directions, latitudinal and meridional (that is, perpendicular to and parallel to the rotational axis of the Earth).

The data presented indicate that a single latitudinal zonality of the Earth exists, applying equally well to the outer gaseous and liquid

envelopes and also to the interior of the planet, almost down to the core. Analogously, series of meridional dislocations exist, also beginning from the outer gaseous and liquid envelopes and continuing almost to the Earth's core. Here we contrast the latitudinal zonality with the meridional division into series.

Consequently, it may be assumed that the symmetry features of our planet which are related to its gravitational field will show up in the gaseous and liquid envelopes of the Earth as well in its solid body, and that these envelopes will definitely have the same symmetry. The atmosphere and hydrosphere are not just air and water, but are aggregates of air and water which are symmetrically constructed in a definite way. Thus, in a way, they constitute liquid and gaseous crystals. In one of his earlier works (1907) Vul'f referred to the terrestrial spheroid as a body possessing a known symmetry. The ocean and the troposphere, moreover, are characterized by this same symmetry. Such is the effect of the gravitational forces under the conditions of terrestrial rotation. That this is the case has already been noted by Usmanov in his reports and articles on meteorology and oceanography.

The symmetry so characteristic of our entire planet is observed in the atmosphere and hydrosphere. Pierre Curie considered symmetry as "a state of the medium in which a given phenomenon takes place". Curie called upon scientists to account for not only the state of the medium but also the state of motion of the given object, as well as the physical factors acting upon it. In our case the motion of the object is its rotation, while the main factor acting upon it is gravity. "The symmetry of the surrounding medium appears to leave an impression upon an object forming in it", states Shafranovskii (1960). For the Earth, the surrounding medium is its gravitational field.

This article began by referring to the book "The Natural Water of the Earth and the Lithosphere", in which it is stated that orogenesis is part of a process of re-formation of the body of the planet. We have explained essentially what this re-formation is during the course of the article, and we have indicated the role played by subcrustal tangential movements in producing mountainous upheavals at the critical meridians and parallels. In the last chapter of the book (pp. 151 ff.), the author states that orogenic processes are explained by the action of the oceans on the continents through the agency of the tidal waves of water. "The natural water of the Earth, therefore, provides a key which can be used to solve the problem of tectogenesis, a problem which cannot be separated from the rotation of the planet". The book goes on to say that "orogenesis is a result of the action of the oceanic tides upon the solid crust of the Earth, via their action upon the continents".

It might be said at this point that we have been guilty of a direct contradiction in our theory. In one place it was stated that dislocations and deformations of the Earth's crust result from the interaction of the terrestrial envelopes, whereas in another place these same deformations are ascribed to the effect of the oceans upon the continents. I shall try to show that no contradiction exists here, and that we have to do just with an approach toward a more specific definition of the concept during the course of its development.

The following must be kept in mind. The hydrosphere and lithosphere are arbitrarily considered to be two different envelopes of the Earth. In reality, however, taken together they constitute parts of a single envelope. The hydrosphere and lithosphere are completely indissoluble, since it is only together that they form the surface of a given level of the terrestrial ellipsoid. If we were to remove the water from this ellipsoid, the ellipsoid would cease to exist at the given level. Moreover, to remove the rock (that is, the lithosphere) instead of the water (that is, the hydrosphere) is completely impossible. Obviously, here we are dealing essentially with parts of a single antipodal structure, and these parts are indivisible; between them an interaction is inevitable. Thus, in addition to what was expressed earlier on this subject, I should now add the following: the interaction of the hydrosphere and lithosphere within the limits of a given level of the ellipsoid is a determining factor constituting a basis for the interaction relating all the envelopes.

This can be illustrated roughly in the following way. The ellipsoid of the Earth is subdivided into the series of levels referred to above. The surface of the ionosphere forms one of the outermost levels. Below it, or deeper into the Earth, is the surface of the troposphere, and beneath the latter lies the combined surface of the hydrosphere and the lithosphere. Finally, the barysphere, the mantle, and the core lie even closer to the Earth's center. It must be taken into account that all these envelopes represent, as it were, levels of ellipsoids. The hydrosphere-lithosphere level, which was just discussed above, we assume to be the most important level and the one which most determines the interaction of the envelopes.

Ocean currents have for a long time been explained as being a consequence of the winds which furrow the surface of the ocean. The currents follow the directions of the winds. In this case the contact between the troposphere and the hydrosphere produces currents. Exactly the same thing occurs at the contact boundaries of the other envelopes: lithosphere and barysphere, and barysphere and mantle.

Other interactions exist between the hydrosphere and the lithosphere. Here there is a contact more intimate than just a contiguity of inner and outer surfaces. This contact, so it seems to us, extends into the depths of the Earth, gradually weakening from higher levels to lower ones, but even at great depths exerting an influence on the relation between the contacting envelopes. Consequently, the central element or link in the interaction of the envelopes is the action of the oceans on the continents, which determines the main features of the entire interaction (namely its direction and rate). Accordingly, the action of the oceans on the continents (the relationship between the two largest megastructures of the planet) is a central phenomenon which determines all the main aspects of the interaction of the envelopes. In other words, the tide-producing processes must be counted as a basic manifestation of this interaction.

In a report presented at the Geographical Society on 27 February 1961, T. D. Reznichenko made use of several examples to show very convincingly that during the warm phases of periods measured in millenia the estuary regions, and also the channels, of rivers flowing latitudinally become shifted toward the north. During periods of cold, on the other hand, the mouths and channels of such rivers shift to the south.

In relation to this, we should also keep in mind Gerenchuk's recent observation that "tectonic disturbances are the primary means for the natural discharge of ground water which ensures the constancy of runoffs required for river formation" (Gerenchuk, 1960, p. 172).

As Gerenchuk has pointed out, rivers do not appear just anywhere. Rather, they always come into being in places where the structure of the land permits their creation. It is not possible to make a river out of any given gully, but only out of gullies which occupy definite places in ancient synclines. Large river systems are always associated with artesian basins and are in fact inseparable from them. This means that tectonic structures determine where river valleys will be located, and that the evolution of the valleys must be affected by the evolution of the structures enclosing them. As Davydov (1955), L'vovich (1938), and others have pointed out, ground water is a very important supply source for rivers. For example, on the Russian plain, ground water supplies on the average over 30% of the total amount of water fed into the rivers. There is some basis for assuming that a shifting of the channels takes place not only for the river and ground water of the alluvium but also for the actual ground water as well.

Gerenchuk notes that "the presence of tectonic structures, as indicated by synclines, faults, upheavals, and folds, with a prevalence of jointing, is a necessary condition for the formation of river valleys" on the Russian Platform (p. 177).

Structural disturbances, together with the outflows of ground water accompanying them, are a prerequisite for rearrangement of the river-system plan. In general, the tectonic forces which appear under the conditions of river erosion are the prime cause of the rearrangement of river systems. River valleys usually form along lines of tectonic disturbances (Gerenchuk, 1960). Consequently, it is quite likely that the shifting of these valleys to new places is also related to the appearance of such disturbances.

On the basis of the foregoing we may state that, when during the course of the Earth's rotation the water of the oceans is shifted first in one direction and then in another, both latitudinally and longitudinally, analogous shiftings of the ground water and the water in rivers take place simultaneously on the continents. Tectonic phenomena contributing to this change also appear. This is a cogent example of the unity and inseparability of the waters of our planet.

Now let us consider the subject from the point of view of surface alluvial plains. In a series of works published between 1930 and 1933, I presented an analysis of this problem. I described two belts of alluvial plains in the Northern Hemisphere: one at the boundaries of the Old World, near the edge of the continental glaciation, and the other around the latitudinal mountain belt at the 35th parallel. The plain belt associated with the mountain glaciations coincides generally with the part of Asia in which are located the rivers described by T. D. Reznichenko as having shifted channels and estuaries.

It was clear to me as early as the thirties that the formation of the alluvial plains in this belt was related to the rotation of the Earth. At that time I studied the Dnieper plain and certain other alluvial plains from the point of view of terrestrial rotation, and I related their genesis to von Baer's law. It appeared quite natural to me that, during the systematic shifting

of the channel toward the right, enormous floodplains must have remained to the left of the channel, which during the evolution of the river system turned into terraced plains (that is, floodplains with different levels).

For some plains this is a valid explanation. However, according to von Baer, who worked out a complete formulation of his law during the course of some decades, there are actually two kinds of alluvial plains, which he called flussbetts and flusstals. The Dnieper Valley is a flusstal, and flusstals can be explained satisfactorily as shiftings to the right according to von Baer's law. Flussbetts, on the other hand, do not have a relation to von Baer's law. Most alluvial plains are of the flussbett type, and since they do not just develop to the right, but rather to both the left and the right of some basic position, there is reason to assume that they do not form accordint to von Baer's law. Von Baer did not discuss this, nor did I discuss it in my articles either. Now, however, after the observations of Reznichenko, I have definitely concluded that plains of this type could not have developed according to von Baer's law; they were also formed in relation to the rotation of the Earth, but by some other means. I advocate the above-mentioned idea of an "intermediate" tectonics which manifests itself in the north of the alluvial plains during warm periods and toward the south during cold periods. Tectonic phenomena of this type ensured an outflow for the water supplying rivers, sometimes from one side of the flussbett and sometimes from the other side, as is the case from the Pripet Polessie, and for the valleys of the Mississippi, the Hwang Ho, and the Amu Dar'ya. This is how I would explain the hydrology of channels of the flussbett type, since von Baer's law does not apply to them, although von Baer thought otherwise.

The positions of ancient latitudinal alluvial flussbetts are determined by the three zones of epeirogenic regions first designated by myself in 1927 and then definitely specified in 1934 (see the figure on p. 3 of Gerenchuk, 1958, and also my chart of epeirogenic movements in the European part of the USSR in Lichkov, 1927 and 1934). On the other hand, Gerenchuk found fault with my scheme (see pp. 17-18 of his work), and he stated that my explanation of "the most recent tectonic movements" for the Russian plain was given without a sufficient tectonic basis. He opposed my scheme on the basis of the ideas expressed by Mirchink (1933, 1936), according to which it is not the zonality of the movements which have taken place during a given epoch that determines their distribution, but rather all of the previous tectonic history of these movements.

However, it is not difficult to show that, in the western part of the territory shown on my chart (on the Volyn-Podol'sk plateau or the L'vov syncline), there is a large area where a new uplift has appeared, rather than something inherited from earlier periods, as in the other parts of the region. This uplift definitely verifies the indicated epeirogenic zonality in just the form indicated by me, and it enables us to indicate the consecutive distribution of artesian basins in this region. In particular, the flusstals described by Reznichenko coincide territorially with the artesian basins around the mountains, as is evident from my 1958 article.

The movements referred to here, it seems to me, were tectonic movements which appeared sometimes at the northern, and sometimes at the southern, edges of the artesian basins around the mountains. Such an interpretation gives the most accurate localization of these movements and assigns them a place in the pattern of symmetry of our planet.

EFERENCES

BALL, R. S. Time and Tide, a Romance of the Moon. — New York, Young. 1899.

BROUNOV, P. I. O prichinakh lednikovykh epokh (The Causes of the Ice Ages). — Priroda, No. 7. 1924.

CLAIRAUT, A. C. Téorie de la figure de la terre, Paris, Durand. 1743 [Russian translation. 1947.]

CURIE, M. Pierre Curie. — New York, Macmillan. 1923 [Russian translation. 1924.]

DARWIN, G. H. The Tides. — Riverside Press, Cambridge. 1898 [Russian translation. 1922.]

DAVYDOV, L. K. Gidrografiya SSSR (The Hydrography of the USSR). Vol. 2. — Izdatel'stvo LGU. 1955.

EIGENSON, M. S. Solnechnaya priroda neravnomernosti vrashcheniya Zemli (The Solar Character of the Irregularity of the Earth's Rotation). — Tsirkulyar L'vovskoi Observatorii, No. 28. 1954.

EIGENSON, M. S. and S. P. KHROMOV. Zonal'nye osobennosti tsirkulyatsii zemnoi atmosfery, kriticheskie paralleli perioda i solnechnaya aktivnost' (Zonal Features of the Circulation of the Earth's Atmosphere, Critical Parallels of the Period, and Solar Activity). — Tsirkulyar L'vovskoi Observatorii, No. 28. 1954.

EIGENSON, M. S. and M. V. STOVAS. Kriticheskie paralleli, shirotnaya zonal'nost' solnechnoi aktivnosti (Critical Parallels and Latitudinal Zonality of the Solar Activity). — Tsirkulyar L'vovskoi Observatorii, No. 23. 1954.

GERENCHUK, K. I. Rechnye sistemy i tektonicheskie struktury (River Systems and Tectonic Structures). — Geologicheskii sbornik L'vovskogo geologicheskogo obschestva pri L'vovskom universitete, 5-6, p. 211. 1958.

GERENCHUK, K. I. Tektonicheskie zakonomernosti v orografii i rechnoi seti Russkoi ravniny (Tectonic Regularities in the Orography and River Network of the Russian Plain). — Zapiski Geograficheskogo obshchestva Soyuza SSR, Novaya Seriya, Vol. 20. 1960.

KATTERFEL'D, G. N. Osnovnye zakonomernosti planetarnogo rel'efa (The Basic Regularities of Planetary Topography). — Uchenye Zapiski Leningradskogo Gosudarstvennogo Pedagogicheskogo instituta imeni A. I. Gertsena. Kafedra Geografii, Vol. 151. Izdatel'stvo LGU. 1958.

KRASOVSKII, F. N. Sovremennye zadachi gradusnykh izmerenii (Modern Problems of Degree Measurements). — Izvestiya AN SSSR, Seriya Geograficheskaya i Geofizicheskaya, No. 3. 1941.

LICHKOV, B. L. Osnovnaya zakonomernost' vekovykh podnyatii i opuskanii zemnoi kory (A Fundamental Regularity of the Secular Upheavals and Subsidences of the Earth's Crust). — Priroda, No. 11. 1927.

LICHKOV, B. L. O zonal'nosti zemletryasenii (The Zonality of Earthquakes). — Priroda, No. 3. 1929.

LICHKOV, B. L. Dvizhenie materikov i klimaty proshlogo Zemli (Continental Movements and the Past Climate of the Earth). — Izdatel'stvo AN SSSR. 1931 (2nd and 3rd editions, 1935; 4th edition. 1936).

LICHKOV, B. L. Ob epirogeticheskikh dvizheniyakh na Russkoi ravnine (Epeirogenic Movements on the Russian Plain). — Trudy Geomorfologicheskogo Instituta AN SSSR, No. 10. 1933.

LICHKOV, B. L. Izmeneniya rel'efa zemnogo shara v svyazi s ego dvizheniyami i energetikoi (Variations of the Topography of the World in Connection with Its Motions and Energetics). — DAN SSSR, **54** (8). 1944.

LICHKOV, B. L. Drevnie oledeneniya i velikie allyuvial'nye ravniny (Ancient Glaciations and Large Alluvial Plains). — Priroda. 1930.

LICHKOV, B. L. Drevnie oledeneniya i velikie allyuvial'nye ravniny proshlogo Zemli (Ancient Glaciations and Large Alluvial Plains of the Earth in the Past). — Izvestiya GGI. 1931.

LICHKOV, B. L. O drevnikh oledeneniyakh i velikikh allyuvial'nykh ravninakh proshlogo Zemli (Ancient Glaciations and Large Alluvial Plains of the Earth in the Past). Parts 1 and 2. — Zapiski GGI, 1931, 1932.

LICHKOV, B. L. Poyasa polesii i proiskhozhdenie osnovnykh elementov rel'efa Russkoi ravniny (Polessie Belts and the Origin of the Main Elements of the Topography of the Russian Plain). — Izvestiya AN SSSR, Seriya Geograficheskaya i Geofizicheskaya, No. 1. 1944.

LICHKOV, B. L. O geologicheskom proshlom evropeiskikh rek (The Geological Past of European Rivers). — Problemy fizicheskoi geografii, sbornik 3, Izdatel'stvo AN SSSR. 1936.

LICHKOV, B. L. Denudatsionnye poverkhnosti i struktury v gornykh vozvyshennostyakh Tadzhikistana (Denudation Surfaces and Structures in the Mountains of Tadzhikistan). — Soobshcheniya Tadzhikskogo Filiala AN SSSR, No. 8. 1948a.

LICHKOV, B. L. Teoriya tangentsial'nogo obrazovaniya gor i shariazhi Al'p (Theory of the Tangential Formation of Mountains and Overthrust Foldings in the Alps). — Vestnik LGU, No. 9. 1948b.

LICHKOV, B. L. K voprosu o znachenii mestnykh bazisov erozii v gidrogeologii (The Significance of Local Erosion Levels in Hydrogeology). — Trudy Laboratorii Gidrogeologicheskikh Problem AN SSSR, Vol. 8. 1948c.

LICHKOV, B. L. O vremeni sozdaniya na Zemle sovremennykh pustyn' i o vremeni poyavleniya v nikh drevnikh okologornykh allyuvial'nykh razlivov i okologornykh artezianskikh basseinov (The Time of Creation on the Earth of Present-Day Deserts and the Time of Appearance in Them of Ancient Alluvial Floods and Artesian Basins around the Mountains). — In: Geologicheskii sbornik L'vovskogo geologicheskogo obshchestva pri L'vovskom universitete, Nos. 5-6. 1953.

LICHKOV, B. L. Prirodnye vody Zemli i litosfera (The Natural Water of the Earth and the Lithosphere). — Leningrad, Izdatel'stvo AN SSSR. 1960.

L'VOVICH, M. I. Opyt klassifikatsii rek SSSR (An Experiment in Classifying the Rivers of the USSR). — Trudy Gidrologicheskogo Instituta, No. 6. 1938.

MAGNITSKII, V. A. O vozmozhnom kharaktere deformatsii v glubokikh sloyakh zemnoi kory i v podkorovom sloe (The Probable Nature of Deformations in the Deep Layers of the Earth's Crust and in the Subcrustal Layer).— Byulleten' Moskovskogo Obshchestva Ispytatelei Prirody, Vol. 23, No. 2. 1948.

MAGNITSKII, V. A. Issledovanie shirokikh voln geoida putem sovmestnogo ispol'zovaniya geodezicheskikh i gravimetricheskikh dannykh (The Study of Latitudinal Waves of the Geoid by Means of the Joint Use of Geodesic and Gravimetric Data).— Izvestiya AN SSSR, Seriya Geograficheskaya i Geofizicheskaya, No. 3. 1948.

MIRCHINK, G. F. Epeirogenicheskie kolebaniya Evropeiskoi chasti SSSR v techenie chetvertichnogo perioda (Epeirogenic Variations in the European Part of the USSR during the Quaternary Period).— Trudy 2-i Mezhdunarodnoi konferentsii ANChPE, No. 2. 1933.

MIRCHINK, G. F. O chetvertichnom orogeneze i epeirogeneze na territorii SSSR (Quaternary Orogenesis and Epeirogenesis in the USSR).— Materialy po Chetvertichnomu Periodu SSSR, No. 1. 1936.

MORAIN, C. Sur la repartition des tremblements de la terre en latitude. — C. R. Acad. Sci. Paris, Vol. 184, No. 10. 1927.

PARIISKII, N. N. Zamechaniya k voprosu o kriticheskikh parallelyakh M. V. Stovasa, k voprosu o solnechnoi obuslovlennosti neregulyarnykh izmenenii skorosti vrashcheniya Zemli (Observations Concerning the Critical Parallels of M. V. Stovas and Concerning a Solar Explanation of Irregular Variations in the Velocity of Rotation of the Earth).— Astronomicheskii Zhurnal, Vol. 32, No. 4. 1956.

SEL'SKII, V. A. Proiskhodit li dvizhenie polyusa (Does a Movement of the Pole Take Place?).— Nauchnye Zapiski L'vovskogo Politekhnicheskogo instituta, No. 3. 1949.

SHAFRANOVSKII, I. I. Lektsii po kristallomorfologii mineralov (Lectures on the Crystallomorphology of Minerals).— Izdatel'stvo LGU. 1960.

SHMIDT, O. Yu. Izbrannye trudy. Geofizika i kosmogoniya (Selected Works. Geophysics and Cosmogony).— Izdatel'stvo AN SSSR. 1960.

STOVAS, M. V. K voprosu o kriticheskikh parallelyakh zemnogo ellipsoida (Critical Parallels of the Terrestrial Ellipsoid). Author's Summary.— Izdatel'stvo LGU. 1951.

STOVAS, M. V. Geomorfologicheskii smysl pervogo i vtorogo ekststentritsitov (The Geomorphological Meaning of the First and Second Eccentricities).— Vestnik LGU, No. 13. 1956.

STOVAS, M. V. Nerivnomirnist' obertaniya Zemly yak planetarno-heomorfolohichnyi ta heotektonichnyi faktory (The Irregularity of the Earth's Rotation as a Planetary-Geomorphological and Geotectonic Factor).— Heolohichnyi Zhurnal AN SSSR, No. 3. 1957 [In Ukrainian].

STOVAS, M. V. K voprosu o shirotnoi zonal'nosti seismiki Zemli (Concerning the Latitudinal Zonality of the Seismic Pattern of the Earth). — Nauchnye doklady vysshei shkoly, seriya geologicheskaya, No. 3. 1958.

STOVAS, M. V. Peremennost' vrashcheniya Zemli i geotektonika (The Variability of the Earth's Rotation and Geotectonics).— In: Geologicheskii sbornik L'vovskogo geologicheskogo obshchestva, Nos. 5-6. 1958.

STOVAS, M. V. Potentsial deformiruyushchikh sil i ego izmenenie s izmeneniem rotatsionnogo rezhima ellipsoida (The Deformation-Force Potential and Its Variation with a Variation in the Rotation Conditions for an Ellipsoid). — Vestnik LGU, No. 1. 1959.

STOVAS, M. V. Pro mozhlyvu periodychnosty vynyknenyya planetarnykh razlomiv ta bazal'tovykh vylyvan' (The Possibility of Periodicity of the Appearance of Planetary Faults and Basaltic Eruptions). — Dopovidi AN URSR, No. 5. 1959 [In Ukrainian].

STOVAS, M. V. De yaky pytanyya 35-i paralleli elipsoida obertanyya (The Question of the 35th Parallel of the Ellipsoid of Rotation). — Dopovidi AN URSR, No. 6. 1959 [In Ukrainian].

STOVAS, M. V. Deformatsiya parametrov ellipsoida s izmeneniem szhatiya (The Deformation of Ellipsoid Parameters with a Variation in Flattening). — Vestnik LGU, No. 13. 1959.

STOVAS, M. V. Neravnomernost' vrashcheniya Zemli kak geotektonicheskii faktor (Irregularity of the Earth's Rotation as a Geotectonic Factor). — Izvestiya Geograficheskogo Obshchestva, No. 4. 1959.

STOVAS, M. V. Pro spryazhenist' transhressii y rehressii (Conjugality of Transgressions and Regressions). — Heolohichnyi Zhurnal AN URSR, Vol. 19, No. 6. 1959 [In Ukrainian].

STOVAS, M. V. Neravnomernost' vrashcheniya Zemli kak geotektonicheskii faktor (Irregularity of the Earth's Rotation as a Geotectonic Factor). Published in China. 1959.

STOVAS, M. V. Solnechnaya aktivnost' i kriticheskie paralleli (Solar Activity and the Critical Parallels). — Mezhdunarodnyi geofizicheskii god. Informatsionnyi Byulleten', No. 2. 1960a.

STOVAS, M. V. Deyaki zakonomirnosti v neohrafichnomu razpodili platformy y skladchatosty (Some Regularities in Geographical Divisions of Platforms and Folds). — Ukrayins'kyi Heolohichnyi Zhurnal 1960b [In Ukrainian].

STOVAS, M. V. Zmishchenyya tochky na poverkhni deformovanoho odnoridnoho nestyslyvoho elipsoida obertanyya pryzm (Shifting of a Point on the Surface of a Deformed Uniform Flatttened Ellipsoid of Rotation of a Prism). — Dopovidi AN URSR, No. 8. 1960c [In Ukrainian].

STOVAS, M. V. Teoriya kriticheskikh parallelei (The Theory of Critical Parallels). Synopses of Reports. — Nauchnaya konferentsiya po voprosam obshchei tsirkulyatsii atmosfery. Trudy konferentsii Instituta prognozov. 1960.

STOYKO, N. Sur les relations de la variation de rotation, l'oscillation libre et les tremblements de la Terre. — C. R. Acad. Sci., Paris, **203** (39). 1936.

USMANOV, R. F. O vliyanii vrashcheniya Zemli na obshchuyu tsirkulyatsiyu atmosfery (The Effect of the Earth's Rotation on the General Atmospheric Circulation). Synopses of Reports. — Nauchnaya konferentsiya po voprosam obshchei tsirkulyatsii atmosfery. Trudy konferentsii Instituta prognozov. 1960.

USMANOV, R. F. Osobennosti pogody i tsirkulyatsii atmosfery v tropikakh i ekvatore (Characteristics of the Weather and the Atmospheric Circulation in the Tropics and at the Equator). — Trudy konferentsii Instituta prognozov. 1960.

VOEIKOV, A. I. Klimaty zemnogo shara (The Climate of the World). (1884). — Izbrannye Sochineniya, Vol. 1. 1948.
VUL'F, Yu. V. Simmetriya i ee proyavlenie v prirode (1907) (Symmetry and Its Manifestation in Nature) (1907). — In: Sbornik statei Yu. V. Vul'fa. Izbrannye raboty po kristallofizike i kristallografii. 1952.

T.D. Reznichenko and S.D. Reznichenko

SOME REGULARITIES IN THE EVOLUTION OF THE EARTH

I. GENERAL THEORETICAL CONSIDERATIONS

Two more or less "universal" factors are usually cited as being responsible for many phenomena and facts related to the evolution of the Earth during the course of geological history. These two factors are climatic changes and tectonic movements. However, no really satisfactory theory has as yet been worked out which enables us to understand these factors, the result being that the corresponding phenomena and facts are very often explained vaguely, unconvincingly, or simply falsely.

In the present article we shall consider a third, very important, factor influencing the evolution of the Earth: the long-period fluctuations in the regime of its diurnal rotation. Essentially, the problem can be formulated as follows: the three factors (climate, diurnal-rotation regime, and tectonics) are mutually related and influence one another in a complex way. A variation in any one of these factors, whatever its cause may be, inevitably entails corresponding variations in each of the others, and many important characteristics of the Earth's evolution are determined by the interaction of these three main determining factors.

How is this relation between climate, diurnal-rotation regime, and tectonics actually effected? What is the mechanism of the interaction between these three factors? Finally, how are these factors related to the many other factors affecting the evolution of the Earth?

First of all, let us discuss briefly the climate of our planet. Theory, observation, and the results of various studies all show convincingly that the continual recurrence of warm and cold periods is a general characteristic of the Earth's evolution. This recurrence is apparently due to both terrestrial and extraterrestrial causes. An entire spectrum of cyclical fluctuations with smaller periods and amplitudes is superimposed onto the cyclical fluctuations whose periods and amplitudes are comparatively large. Observations also indicate that fluctuations in climate, long-term as well as short-term, have the same phase in both the Northern and Southern Hemispheres.

From the point of view of philosophy, "it is impossible to assume that the climate does not change, since everything in nature evolves and passes from one qualitative state to another" (Kalesnik, 1957). The following factors all vary during the course of time: the amount of heat transferred from the interior of the Earth to its surface; the energy-radiating capacities of extraterrestrial bodies; the physical properties of the medium occupying the space between the Earth's surface and

energy-radiating extraterrestrial bodies; the albedo of the Earth; the general planetary shape of the Earth; and the vertical-horizontal ratio between water and dry land, which determines the nature of the hydro-atmospheric circulation. Consequently, the climate, which is affected by all these factors, must vary with time as well. The variations in some climatogenic factors (or even in all the factors taken together) may appear to be irreversible at the end of a quite long period of time, but within the period itself these variations will have the nature of fluctuations.

As a direct result of the climatic changes, the water mass on the surface of the Earth undergoes periodic redistributions relative to the poles and the equator (that is, relative to the rotation axis). Thus, once a shoreline appeared (or, in other words, once the separation of the Earth's surface into dry land and water was completed), the presence of water in the solid state became possible. Accordingly, in many instances the natural conditions were such that snow, firn, and ice accumulated (or melted) to some extent or other, mostly in the high latitudes (around the poles) but also in the low latitudes (around the equator).

Such redistributions of the mass of the Earth alter the moment of inertia of the planet, and thus (since the product JW remains constant) its angular velocity as well. For example, if 3.2 cm of the ice cover of Antarctica melts during the summer, part of the water which is formed thereby will flow toward the equator. If this water were distributed uniformly over the surface of the sea, it would form a layer 0.12 cm thick. Such a small elevation of the water surface at the equator would naturally be difficult to observe directly, but even this minute change in the level of the sea would affect the velocity of rotation of the Earth. If this same change took place during 100 successive years, the rotation of the Earth would slow down by 18 seconds. A cold winter, on the other hand, causing accumulation of ice at the poles, has just the opposite effect: it makes the Earth rotate faster.

Accordingly, we can imagine the magnitude of the fluctuations in the rotational regime of the Earth caused in the past by redistributions of the water masses on the Earth's surface. For example, during the Quaternary period, at the time of maximum glaciation, the level of the World Ocean may have been more than 130 to 150 meters lower than it is at present. Thus the diurnal-rotation regime of the Earth is largely a function of the climate.

The correctness of this conclusion is confirmed by certain factual data. Observations indicate that the secular accelerations of the average motions of the Sun and the Moon (and thus the secular changes in the rotational regime of the Earth) cannot be explained in terms of a single tidal mechanism. For the present epoch (the last 2000 to 2500 years), for example, a secular acceleration of the Earth's rotation must be assumed in addition to the secular tidal slowing down which is known to have taken place. This acceleration component of the change in the diurnal rotation can be assumed to be climatic in origin.

The following conclusions of Maksimov are noteworthy with respect to the relation between climate and the rotation of the Earth: "... the simultaneity of the changes in the rotational speed of the Earth which took place during the last centuries, on the one hand, and the changes in the main climatic characteristics of the polar regions, on the other, is an

indubitable and very interesting fact. For the Arctic Ocean, in particular, it is especially significant that the changes in the Earth's rotational velocity were simultaneous with large-scale variations in the overall iciness of the polar seas. This fact in itself deserves a detailed study" (Maksimov, 1960, p. 14). "A simple comparison of the long-term variations in the Earth's rotational velocity with the index of atmospheric circulation and the circulation of the ocean in the Northern Hemisphere shows a definite relation between large-scale climatic changes and variations in the rotational velocity. The following two relations are important with respect to marine phenomena: the correlation between variations in the rotational velocity of the Earth and changes in the overall iciness of the Arctic Ocean; and the correlation between variations in the rotational velocity and long-term changes in the height of mean sea level in the northern parts of the Atlantic and Pacific Oceans" (Maksimov, 1960, p. 12). "The secular fluctuations (periods of 200 or 300 years) in the iciness of the northern part of the Atlantic, in the continental quality of the climate of western Europe, and in the mean sea-level height of the Caspian Sea, during the last three centuries, were in phase with the variations in the rotational velocity of the Earth" (Maksimov, 1954, p. 75).

Now let us consider how tectonics depends on the diurnal-rotation regime. Any variation in the rotational velocity of the Earth will cause a regular change in the shape of the planet, so as to make it conform completely to the new rotational regime; as a result, gravitational equilibrium will be re-established. In other words, the world will pulsate along its diurnal-rotation axis, sometimes becoming more ellipsoidal and sometimes becoming less ellipsoidal. As a result of these transformations of the planetary figure, various tectonic phenomena are produced, which serve as a unique means of relieving the excess physico-mechanical stresses. These phenomena take place at the expense of the weakest crustal and subcrustal regions of the Earth*.

The Earth's crust, and perhaps part of the mantle as well, has a non-uniform horizontal structure and consists of a great number of more or less rigid blocks which are joined together at comparatively weak regions [contacts]. Because of this, the localization and direction of dislocations will in general be determined by the dimensions, configurations, and strengths of the blocks, and also by the relative weakness of the regions of the Earth's crust located at the contacts between the blocks.

When the rotation of the Earth slows down, the shape of the planet becomes less ellipsoidal, because the centrifugal forces are smaller. Since for a body of given volume the sphere has the least surface area, the Earth will then appear to be in a contraction phase. Areas of the crustal layer will become redistributed, and there will be an efflux of subcrustal material from the equatorial bulge of the Earth toward the polar regions. Tectonic movements characteristic of a contracting surface of the Earth will take place in the crust, the movements being attenuated gradually with depth.

When the diurnal rotation of the Earth is accelerated, on the other hand, the increase in the centrifugal forces makes the planet more

* During the present "quiet" geologic epoch, more than 100,000 earthquakes take place in the world each year, and about 100 of these can be considered large.

elliptical in shape. At this time the Earth appears to be in a phase of expansion, and material is transferred from high latitudes to low latitudes. Tectonic movements characteristic of an expanding planetary surface then take place in the Earth's crust*. During the expansion stage the area of the crust will increase, as a result of the outpouring of subcrustal material into faults and cracks which have been formed. It may be that these newly appearing parts of the Earth's crust subsequently become stronger than some of the "old" parts.

If this is indeed the case, then it implies the following interesting regularity in the evolution of the Earth's crust: as time goes by, the crust is apparently renewed during the expansion stages, as a result of the appearance of "new" regions, which later become the ocean floor. During the contraction stages, on the other hand, the crust becomes thicker because of the "old" regions. Could this not have been the means by which the Earth's surface became differentiated into continents and ocean basins?

In general, the fluctuating inertial-gravitational forces which cause the world to pulsate along its diurnal-rotation axis give rise to mainly horizontal tectonic stresses. However, it must be remembered that climatic changes and oscillations of the Earth's angular velocity also produce forces which give rise to tectonic movements which are mainly vertical. These forces are isostatic in nature, and they appear as a result of the redistribution of the water masses on the Earth's surface in the meridional direction (the appearance or disappearance of solid-phase water, and shifting of the hydrosphere under the influence of the centrifugal diurnal-rotation forces). Consequently, the general planetary hypsometric curve varies with time, since the relative elevations of the ocean floor and the continents vary periodically, being different in different regions.

Thus, geotectonic movements are mainly the results of two phenomena involving the entire planet: the axial pulsation of the world caused by variations in its angular velocity; and the isostatic equalization associated with an increase or decrease in the water stress on different segments of the Earth's surface.

The various tectonic movements will result in a rearrangement of the structure of the Earth, a transformation of its surface topography, and a consequent variation in the vertical-horizontal ratios between water and dry land. In addition (and this should be emphasized), the ratio between water and dry land will not only be determined by the dislocation movements but also by the shift of the hydrosphere relative to the lithosphere, resulting from variations in the centrifugal diurnal-rotation forces. Thus, this ratio is determined directly by the tectonics, and also by the diurnal-rotation regime. However, the variations in the vertical-horizontal ratio between dry land and water are still the main factor leading to a planet-wide rearrangement of the hydroatmospheric circulation, and thus giving rise to new climatic conditions.

On the basis of all the foregoing, we can draw the following conclusion: a definite cause-effect relationship exists between the three main factors influencing the evolution of the Earth (climate, diurnal-rotation regime, and tectonics). Periodic redistributions of the water mass relative to the diurnal-rotation axis (as a result of hydroatmospheric processes driven by the solar thermal energy) are the chief cause of the relation-interaction between these factors. The main elements of the mechanism responsible

* Of course, variations in the Earth's rotational regime are not the only cause of tectonic movements.

for redistribution of the water mass on the Earth's surface are: the ellipsoidal shape of the Earth (the curvature of its surface); the presence of an atmosphere; the arrival of thermal energy from the Sun; and the presence of cold in interplanetary space. This mechanism can be represented as a kind of heat engine, with a planetary boiler in the low latitudes and a refrigerator in the high latitudes.

Let us denote the cause-effect relationship between climate, diurnal-rotation regime, and tectonics as the first-order regularity in the evolution of our planet.

The three envelopes of the Earth (atmosphere, hydrosphere, and lithosphere) will obviously react in different ways to changes in the rotational regime of the Earth. The hydrosphere, which is more mobile, will assume its new shape quickly. The lithosphere, on the other hand, will change shape only after some lag period, as determined by the physicomechanical properties which govern the relaxation time. The atmosphere, whose rotational regime is also modified (by friction), changes shape as well, but not at the same time as the hydrosphere and the lithosphere. Thus, by virtue of the differences in the physicomechanical properties of the geospheres, the figure of the Earth will at any given moment have a kind of triple nature, as a result of fluctuations in the length of the terrestrial day.

The degrees of flattening of the lithosphere, hydrosphere, and atmosphere corresponding to their new rotational regimes will not be the same. The oblatenesses of all three geospheres would be identical only if the rotational velocity of the Earth remained constant for a quite long period. With respect to the dynamics of the Earth, this means that any fluctuation in the diurnal velocity gives rise to a corresponding "triple pulsation" in the shape of the planet along its rotation axis. The theoretical considerations presented above, and also observational data, indicate that the length of the day varies. Consequently, there is no reason to doubt the existence of out-of-phase pulsations of the geospheres along the axis of diurnal rotation. Obviously, these pulsations are effected as a result of the arrival at the Earth of solar thermal energy.

Let us denote this out-of-phase pulsation of the geospheres (lithosphere, hydrosphere, and atmosphere) along their diurnal-rotation axis as the second-order regularity in the evolution of the Earth.

"...the water of the Earth constitutes a single entity, all parts of which are inseparable from one another in nature, because of the close relation between them... It is just because water possesses such special properties (unusual mobility, enormous molecular and gravitational forces) that it may be thought of as a single entity. This characteristic has determined the exceptional role of water in the history of our planet and also determines its role at present, a role which is (and was in the past) a very active one" (Lichkov, 1959, pp. 107-108).

In accordance with this, the hydrosphere may be assumed to react to variations in the rotational regime of the Earth as a single entity. Fluctuations in the length of the day cause the hydrosphere to shift relative to the lithosphere, sometimes equatorward and sometimes poleward, and the coastline will everywhere be changed correspondingly.

Let us imagine that the rectilinear coast of a continent lies exactly parallel to one of the meridians, from the equator to the pole, and that

tide gauges are placed uniformly along the entire coast. Let us also assume that the degree of flattening of the lithosphere remains constant even though there is a change in the length of the day. Then, if the angular velocity of the Earth increases, the tide gauges will show, beginning at some specific latitude, a regular lowering of sea level toward the pole and a corresponding elevation of sea level in the direction of the equator. If the diurnal rotation of the Earth slows down, on the other hand, the tide-gauge readings will be just the opposite, so that any variations in the rotational regime of the planet will be clearly indicated. Next let us assume that the land extends in a rather narrow, long strip along one of the parallels in the middle latitudes. In this case, an increase in the rotational velocity of the Earth will bring about an ingression of the sea along the north coast, since a water "overflow" will occur as a result of the increased centrifugal forces (for example, along the north coast of the Soviet Union, along the Mediterranean coast of Africa, etc.). For a slowing down of the diurnal rotation, on the other hand, this effect will be observed at the south coast, due to the decrease in the centrifugal forces (for example, along the coast of the Gulf of Mexico, along the north coast of the Mediterranean, etc.). The sea-level variations occasioned by the "overflow" of the water will be a minimum (zero) at the pole and the equator and a maximum in the middle latitudes.

Existing hypotheses give different explanations for the fluctuations in the levels of the oceans and seas (that is, for the changes in the mutual positions of the land and the water areas), but they do not offer any definitive answer to this complex question. In oceanography the observation system is set up in such a way that the instruments are based on immobile segments of the Earth's crust, and the level of the sea is taken as the moving object. In geology, on the other hand, sea level is taken as the constant element, and displacements of the Earth's crust are observed relative to it by means of a system of depth gauges. Since neither of these two observation systems is actually at rest, a solution can be found only by means of combined methods. To do this, in addition to the factors which are known to influence the sea level (such as tectonic phenomena, tides, winds, atmospheric pressure, temperature, precipitation, erosion, river runoff, etc.), certain other no less significant factors must be taken into account (for instance, the shifting of the hydrosphere relative to the lithosphere and the "overflow" of water as a result of changes in the magnitude of the Earth's centrifugal forces). All these factors can operate in different directions, and we are only able to observe their resultant effect.

The effect which fluctuations in the rotational regime have on the shifting of the coastline must be universal and must extend over the entire surface of the spheroid. Other effects, on the contrary, are usually localized within definite regions or else are minor. In addition, the division of the Earth's surface into regions of regression and transgression of the oceans must manifest itself as a preponderance of either inward or outward shifts of the coast in different latitudes of the spheroid. In spite of this, so far it has not been possible to draw any important conclusions concerning the rotational regime of the Earth just on the basis of coastline shifts; there are too many masking factors which influence these shifts.

There is one hydrospheric phenomenon, however, which clearly and unambiguously indicates the existence of long-period variations in the

length of the day; this is the planet-wide rearrangement of the drainage system.

The rotational forces which affect the entire hydrosphere as a whole (and shift it relative to the lithosphere) will naturally have a corresponding effect on parts of the hydrosphere considered separately (for instance, on the ground water and surface water of the continents). Thus, the whole hydrographic system of the Earth must periodically undergo a more or less thorough rearrangement. Such a rearrangement will naturally take place under the influence of other factors as well, for example, as a result of tectonic movements, fluctuations of the base level, filling in of individual parts of channels and basins with river sediment, human intervention, etc. However, there is an important fundamental difference between the effects of all these other factors and the effect of the rotational forces. The rearrangement of the drainage system caused by variations in the rotational regime of the Earth takes place regularly and on a world-wide scale, its intensity being the greatest in the middle latitudes. The effects of the various other factors, on the other hand, are neither regular nor universal.

When the Earth's rotation on its axis slows down, the whole hydrosphere (oceans and seas, lakes and rivers, ground and surface water) has a tendency to shift toward the poles, due to the decrease in the centrifugal forces. The water divides of all basins are shifted in the direction of the equator, and the poleward liquid and solid runoff increases. For all rivers the erosion of the northern banks will increase in the Northern Hemisphere and that of the southern banks will increase in the Southern Hemisphere. In individual parts of rivers, especially in their lower reaches, there is an increased tendency toward breaking through the banks, leading to changes in the direction of the flow, and consequently to shifts (generally poleward) in the locations of the deltas and mouths. As a result, the so-called "wandering" rivers and lakes are formed.

For rivers flowing toward the equator, the following takes place: the stream velocity is reduced; the accumulation of sediments and the filling in of river valleys with them increases; the bed becomes more sinuous and unsteady; the mouth becomes more branched, with shallows; and the rate of advance of the delta into the standing-water body decreases. Consequently, rivers of this type will appear to be senile.

Rivers flowing poleward, however, will cut their way into the bed more strongly, making it deeper and cutting out stream terraces; the stream velocity will increase; the bed will become more rectilinear and more stable; and the rate of advance of the delta will increase. Rivers of this type will in general appear to be in a state of rejuvenation. When the diurnal rotation of the Earth speeds up, on the other hand, the centrifugal forces become greater and all the aging phenomena described previously will be observed for these rivers.

Let us now illustrate how a change in the direction of a river takes place, and how river mouths and deltas become modified. We shall also indicate how in some cases bodies of standing water disappear and are replaced by new ones. Consider a river flowing in a latitudinal direction. In the plain portion of its lower reaches the river divides into two branches, one northern and one southern. When the diurnal-rotation velocity of the Earth increases, the "base supply" of the river (the ground water of the alluvial valley-depression through which the river flows) becomes shifted

toward the equator. Consequently, the water table in the part of the valley through which the northern branch flows is lowered. The discharge of water and the stream velocity are reduced, as a result of the increase in infiltration losses; thus there is a progressive increase in sediment accumulation along the river. Drainage to a body of standing water becomes more difficult, and the branch enters into a stage of natural drying up. This cannot but have a direct effect on the regime (and on the general fate) of the body of water into which the river discharges, especially if it is landlocked.

Depending on the role played in the overall water balance of the water body by the water influx in the given branch (river), the level of this body will either be reduced accordingly and the water will become brackish, or else it will dry up completely, leaving a salt depression. The water table in the part of the valley through which the southern branch flows, on the other hand, will be raised, since the infiltration losses there will be diminished. Accordingly, the amount of water and the stream velocity in this branch will increase, and downcutting of the channel bed will begin. Thus, the direction of the river will have a tendency to shift toward the equator. Obviously, if the diurnal rotation of the Earth slows down, the northern and southern branches of the river will exchange roles, and the direction of the river will be shifted poleward.

At this point we should note the following. Fluctuations in the amount of solid suspended matter carried out by the continental water in the directions of the pole and the equator are caused by the irregularity of the Earth's rotation. However, just as in the case of the shifting of water masses in these directions, there will be a reverse effect on the diurnal-rotation velocity as well. Thus, when the rotation slows down, the poleward transfer of masses of sedimentary rock will increase, causing a decrease in the moment of inertia and a corresponding rise in the diurnal-rotation velocity. An increase in the diurnal velocity, on the other hand, leads to a greater transfer of sedimentary masses toward the equator; thus, the moment of inertia increases and the velocity is reduced accordingly. The effect (on the diurnal-rotation velocity) of a fluctuation in the amount of sedimentary rock transported meridionally by the continental water, as a result of irregularity of the diurnal rotation, can thus be summed up as follows: it is as if a gigantic inertial flywheel were operating, which tends to reduce the angular velocity of the Earth when it increases and to accelerate the rotation when it slows down.

Inconstancy of the magnitude of the centrifugal diurnal-rotation forces is one of the main factors responsible for the formation of vast alluvial plains on the Earth's surface. During epochs in which the climate is cooler, the angular velocity of the Earth increases as a result of the formation, predominantly in the high latitudes, of ice; consequently, during these epochs the directions of surface-water flows have a tendency to shift toward the equator. The southern parts of plains will become wetter, and depressions in them will be filled in more intensively with solid deposits than is the case for the northern parts. During these periods aeolian processes develop extensively in the northern parts of plains, particularly under arid conditions.

During epochs of warmer climate, the diurnal-rotation velocity decreases as a result of the transformation of ice into liquid water and the transference of much of the water to the low latitudes. The processes

taking place in the southern and northern parts of plains will then be the opposite of those described above. Consequently, the centrifugal forces of the Earth, which vary periodically in magnitude, alter the directions of the water flows, shifting them from the southern parts of plains to the northern parts and vice versa. Operating in conjunction with wind forces, they level off plains and make them more or less horizontal, producing the corresponding microrelief.

Periodic rearrangements of the drainage system on a planet-wide scale are thus caused by axial pulsations of the entire hydrosphere relative to the lithosphere, as a result of variations in the rotational regime of the Earth. Let us call these rearrangements the third-order regularity in the evolution of the Earth.*

In addition to the three main factors (climate, diurnal-rotation regime, and tectonics), there are many other things which affect the evolution of the Earth, and they may be either terrestrial or extraterrestrial in origin. Table 1 shows the general scheme of the interactions between the main factors. The large circle in the middle (1), with the three smaller circles (2, 3, and 4) around it, represents the first-order regularity in the evolution of the Earth (the relation-interaction between the three main factors: climate, diurnal-rotation regime, and tectonics). The three main factors interact in such a way that any change in one of the factors, no matter what its cause (see squares 5, 6, 7, and 8), must give rise to corresponding changes in each of the others.

The interaction between the three main factors is effected by means of periodic redistributions of the water masses on the Earth's surface, the ultimate cause of the interaction being the thermal energy of the Sun (see square 9). Periodic variations in the diurnal-rotation regime of the Earth give rise to out-of-phase pulsations of the geospheres (atmosphere, hydrosphere, and lithosphere). We have called this "triple pulsation" of the geospheres the second-order regularity in the evolution of the Earth (see circle 10). The out-of-phase pulsation of the hydrosphere and lithosphere leads to periodic rearrangements of the drainage system on a planet-wide scale, a phenomenon which we have designated as the third-order regularity in the evolution of the Earth (see circle 11). Local factors may also influence the rearrangement of the drainage system (see square 12).

II. SOME PHYSICOGEOGRAPHIC FACTS

Our third-order regularity in the evolution of the Earth was formulated on a purely theoretical basis. Does the long-term development of the Earth's drainage system really obey this regularity? In order to answer

* The inertial force is perpendicular to the axis of the Earth. The magnitude of this force is given by the formula: $f=mw^2R\cos\varphi$, where m is the mass of the body, w is the angular velocity of diurnal rotation, R is the radius of the Earth, and f is the geographic latitude of the body.

The force f can be divided into two components: $f_1=mw^2R\cos\varphi$, directed vertically outward and changing the gravitational force in magnitude only; and $f_2=mw^2R\cos\varphi,\sin\varphi$, directed horizontally and changing the force of gravity in direction only.

Clearly, variations in the horizontal component of the inertial force will also affect the rearrangement of the drainage system. Actually, this force and its variations are relatively small, but if it acts in the same direction for a long time it may bring about channel processes and other hydrological processes involving progressive changes, which can have considerable effects on the rearrangement of the drainage system.

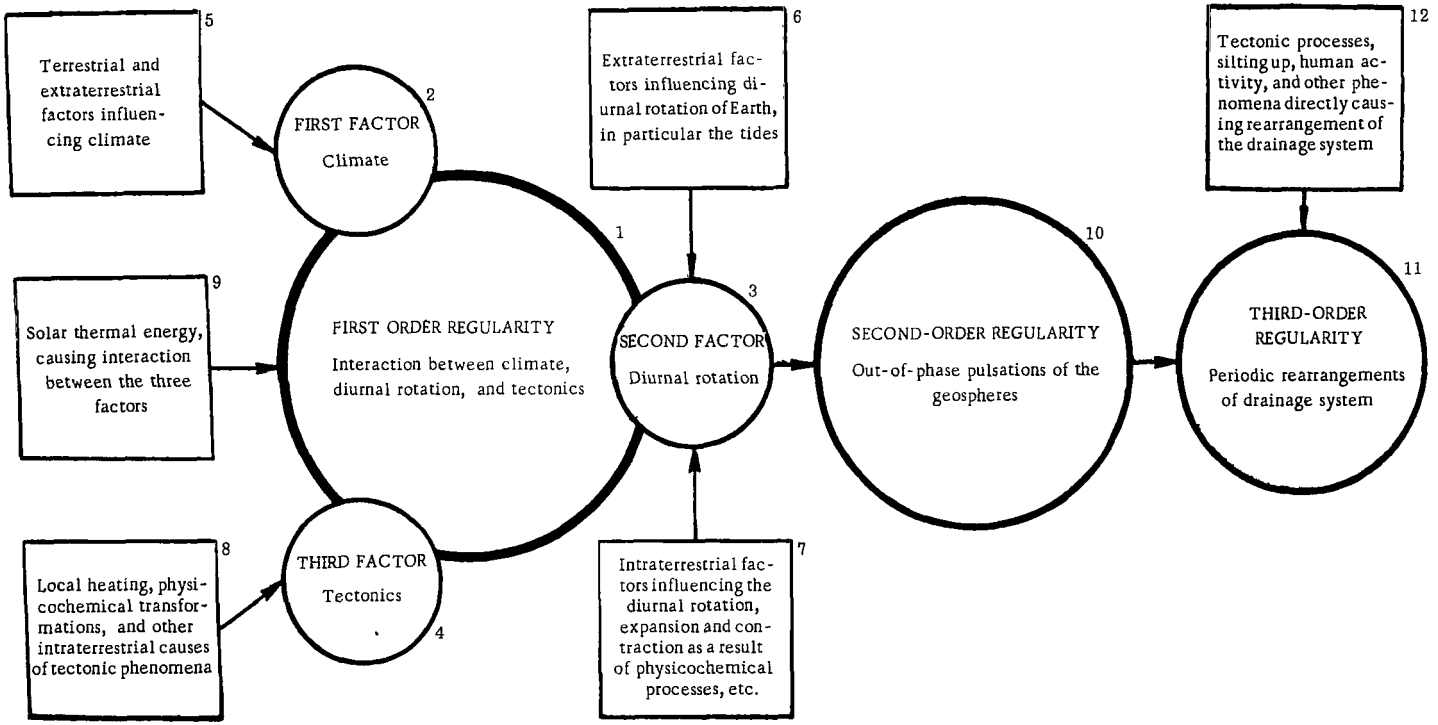


TABLE 1. The interrelation between the main factors influencing the evolution of the Earth.

this question, let us consider what different authors have said about the evolutionary history of certain rivers and water bodies during the last 4500 years or so. For the time being let us look only at this time interval, for the following reasons: first, this is a long enough time to verify the correctness of the corresponding generalizations; second, we have a more or less reliable history of climatic fluctuations for this period.

"A direct analysis of numerous physicogeographic phenomena has made it possible to establish the absolute chronology of the last three periods of changing wetness of the continents of the Northern Hemisphere... It turns out that the period of greatest wetness of the territories and worsening of the climatic conditions (according to the 1850-year cycle) is followed, after a lag of about 100 years, by a phase of general advancement of mountain glaciers, in the wake of their previous general large-scale retreat" (Shnitnikov, 1953). Moreover, studies in Antarctica have shown that during the present period of warm climate the Antarctic glacial cover is retreating synchronously with the retreat of the great majority of glaciers in the world. Apparently, during other epochs as well, climatic warming and cooling took place simultaneously in the two hemispheres.

During the last 4500 years three periods of quite cool climate alternated with three periods of quite warm climate:

the first cool period had a maximum at about the middle of the third millenium B.C. (end of Neolithic and beginning of Eneolithic), and corresponded to mountain glaciation in the Daunian stage;

the second cool period had a maximum about the middle of the first millenium B.C. (antiquity), and corresponded to mountain glaciation in the Egesen stage;

the third cool period had a maximum about the middle of the present millenium (the late Middle Ages), and corresponded to mountain glaciation in the Fernau stage;

the first warm period had a maximum about the middle of the second millenium B.C. (Bronze Age), and corresponded to a subboreal-xerothermic period of optimum climate;

the second warm period had a maximum at the beginning of the second half of the first millenium A.D. (the early Middle Ages), and corresponded to a minor climatic optimum (as this period is called by certain authors);

the third warm period is now in progress, and the maximum has apparently not yet occurred.

It was pointed out above that the water mass of the Earth becomes redistributed (to some degree) relative to the polar and equatorial regions, as a result of climatic fluctuation. The vertical-horizontal ratio between dry land and water in the present geologic epoch is such that an increase in the water mass takes place during periods of climatic cooling, because of the solid water formed, predominantly in high-latitude continental areas; this leads to an increase in the diurnal velocity of the Earth. Climatic warming, on the other hand, will result in an increased mass of water in the low latitudes (since solid water is converted into liquid water), and the rotational velocity of the Earth will decrease.

Thus, to sum up, during the cold periods of the last 4500 years (maximum cooling took place about half way through the third and first millenia B.C. and the second millenium A.D.), the diurnal-rotation velocity of the Earth was relatively high. During the warm periods,

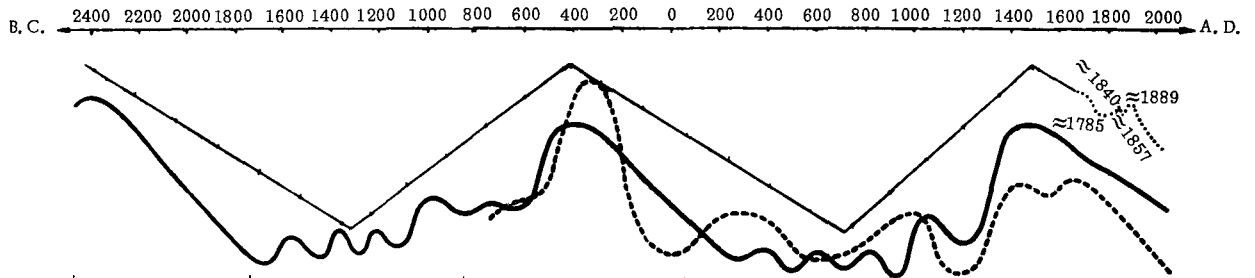
accordingly (maximum warming took place at about the middle of the second millenium B. C. and at the beginning of the second half of the first millenium A. D.), this velocity was relatively low. The maximum warming of the present warm period has apparently not yet been attained. If the 1850-year period of climatic fluctuations established by Shnitnikov actually exists (that is, if the periodic time intervals are equal), then this maximum should occur around the middle of the third millenium A. D., closer to the beginning of the millenium. Consequently, until approximately this time, the general, spasmodic, progressive slowing down of the Earth's diurnal rotation should continue.

Factual data on the evolutionary histories of numerous rivers and water bodies show convincingly that during the last 4500 years the drainage system of the Earth has gone through stages of more or less considerable rearrangement. These rearrangements took place simultaneously with the fluctuations in climate, and thus simultaneously with the fluctuations in the diurnal-rotation regime of the Earth. With the onset of a period of climatic cooling, the rotational velocity of the Earth began to increase, and due to the greater centrifugal forces the drainage system became rearranged in conjunction with the general equatorward shift of all the water. This sort of rearrangement of the drainage system took place during each of the three cold periods. With the onset of a period of climatic warming, the diurnal velocity of the Earth began to decrease, and by virtue of the diminished centrifugal forces the drainage system was rearranged in conjunction with the general shift of water toward the poles. This sort of rearrangement of the drainage system took place during each of the three warm periods (present period included).

In our choice of the rivers and water bodies to be studied, we were guided by certain considerations. First of all, the chronological evolutionary histories of the latter had to be specified somehow or other, by means of data for as long a period as possible. Second, the rivers and water bodies had to be located in the middle latitudes, where the effect of the centrifugal forces is a maximum and where the effect of glaciological loading and unloading is in practice very small. Third, the rivers selected had to flow latitudinally, since in this case their migration shows up the most clearly.

Of all the objects studied by us, the following best satisfied the above conditions: the Black Sea and Caspian Sea, and the Hwang Ho, Amu Dar'ya, Syr Dar'ya, Kura, Kuban', and Don rivers. The effect on the rearrangement of the drainage system of such well-known factors as the quantity and rate of moisture arrival at the surface of the land, the conditions of runoff of this water, the resistance of the land surface, tectonic movements, human intervention, etc. will not be considered at all here. The effects of all these factors will be superimposed onto the periodic rearrangements of the drainage system established by us, but they will not change the general trend of the rearrangements.

Some data on the level fluctuations in individual water bodies and the migrations of certain rivers in their lower reaches are given in Table 2. These variations are compared in the table with the climatic changes (and thus with the fluctuations in the diurnal rotation of the Earth) during the last 4500 years. The water-level variations and river migrations are compared with a combined graph showing the wetness in the Northern Hemisphere (according to Shnitnikov) and the fluctuations in the level of



First cold period	First warm period	Second cold period	Second warm period	Third cold period	Third warm period
Maximum cooling about middle of III millenium B.C. Corresponds to mountain glaciation in Daunian stage. Day shortened. Rivers which deviated equatorward: counterclockwise: Amu Dar'ya. Reservoirs with lower levels: Azov — Black Sea Basin. Reservoirs with higher levels: Caspian Sea	Maximum warming in second half of II millenium B.C. Corresponds to climatic optimum (subboreal period). Day lower levels: Rivers which deviated poleward: clockwise: Zeravshan, Amu Dar'ya, Atrek, counterclockwise: Hwang Ho. Reservoirs with higher levels: Azov — Black Sea Basin Reservoirs with lower levels: Caspian Sea	Maximum cooling about middle of I millenium B. C. Corresponds to mountain glaciation in Egesen stage. Day shortened. Rivers which deviated equatorward: counterclockwise: Zeravshan, Syr Dar'ya, Amu Dar'ya, Atrek, Kuban', Don, clockwise: Hwang Ho. Reservoirs with lower levels: Northern Lop Nor, Azov — Black Sea Basin, northern part of Mediterranean. Reservoirs with higher levels: Southern Lop Nor, Caspian Sea	Maximum warming at beginning of second half of I millenium A.D. Corresponds to minor climatic optimum. Day lengthened. Rivers which deviated poleward: clockwise: Zeravshan, Syr Dar'ya, Amu Dar'ya, Atrek, Kuban', Don; counterclockwise: Hwang Ho. Reservoirs with higher levels: Northern Lop Nor, Azov – Black Sea Basin, northern part of Mediterranean. Reservoirs with lower levels: Southern Lop Nor, Caspian Sea	Maximum cooling about middle of II millenium A.D. Corresponds to mountain glaciation in Fernau stage. Day shortened. Rivers which deviated equatorward: counterclockwise: Halhain Gol, Manass, Ili, Nura, Indus, Zeravshan, Syr Dar'ya, Amu Dar'ya, Rioni, Kuban', Don, Neman, clockwise: Hwang Ho, Edsin Gol, Tarim, Konche Dar'ya, Khaidik Gol, Kura, Dniester, Danube. Reservoirs with lower levels: northeastern part of lake Baikal, Northern Lop Nor, Baghrash Köl, Ikhe Khak, northeastern part of Lake Balkhash, Azov – Black Sea Basin, northern part of Mediterranean. Reservoirs with higher levels: Southern Lop Nor, Ayran Köl, southwestern part of Lake Balkhash, Lakes Tengiz and Kurgal'dzhin, Caspian Sea	Maximum warming probably somewhere in first half of III millenium A.D. Corresponds in its beginning to present warming up. Day lengthened. Rivers which deviated poleward: clockwise: Halhain Gol, Manhass, Ili, Nura, Indus, Zeravshan, Syr Dar'ya, Amu Dar'ya, Rioni; Kuban', Don, Neman; counterclockwise: Hwang Ho, Edsin Gol, Tarim, Konche Dar'ya, Khaidik Gol, Kura, Dniester, Danube. Reservoirs with higher levels: northeastern part of Lake Baikal, Northern Lop Nor, Baghrash Köl, Ikhe Khak, northeastern part of Lake Balkash, Aral Sea, Azov-Black Sea Basin, northern part of Mediterranean. Reservoirs with lower levels: southern Lop Nor, Ayran Köl, southwestern part of Lake Balkhash, Lakes Tengiz and Kurgal'dzhin, Caspian Sea

Table 2. Synchronicity of the millenial climatic fluctuations (and thus of the millenial fluctuations in the Earth's diurnal-rotation velocity) and the periodic rearrangements of the drainage system during the last 4500 years. Combined graph from Tsekhanskii, 1959: solid curve shows wetness fluctuations in Northern Hemisphere (according to Shnitnikov); dashed curve shows fluctuations in level of Caspian Sea (according to Apollov); fine line with dots at end shows fluctuations in diurnal-rotation velocity (constructed schematically from observational data beginning with 1640).

the Caspian (according to Apollov). The combined graph was taken from Tsekhanskii, 1959, p. 199. The probable climatically induced fluctuations in the Earth's angular velocity are also shown on the graph. Finally, by means of a very schematic curve for the variations in the rotational regime of the Earth, we have endeavored to represent the observational data for the last 300 years (Martynov, 1961).

Unfortunately, the size of the present article does not permit a complete, detailed presentation of the results of our studies concerning the histories of rivers and water bodies (see table). Therefore, we shall limit ourselves to a few general observations about each object, and in certain cases we shall present extracts and diagrams taken from the works of other authors, together with an indication of the main references on the subject. For the sake of brevity, it will not be repeated in each instance that the long-period fluctuations in the diurnal-rotation regime, caused by the corresponding climatic changes, are the direct cause of the river migration and the variations in water level. It will simply be stated that the latter variations are the result of the change in climate (the onset of a warm or cold period). The rivers and water bodies will be considered successively, beginning with those in the east and passing to those in the west.

The Hwang Ho. The periodic migration of the Hwang Ho is depicted graphically in Figure 1. During each of the three warm periods, including the present one, the river deviated toward its left (poleward), passing to the north of the Shantung Peninsula and discharging into the Po Hai Gulf. In the first warm period (Bronze Age) the river turned almost due north at its outflow from the mountains. It then picked up the Peh Ho and Lwan Ho tributaries, flowed to the northern part of the Great China Plain, east of Peking, and discharged into the Liaotung Gulf at 39°30'N. This course of the river was the closest to a north-meridional one, if we take into account the conditions in the locality through which the channel passed at this time. It should be noted that from that time up to the present the course of the river did not ever become as meridional as this again.

Interestingly enough, during this same warm period, the Amu Dar'ya, which is located at almost the other end of Asia, also attained its maximum poleward deviation (in this case the shift was to the right), the course of the river then being the most north-meridional. At this time the Amu Dar'ya waters flowed along the Akcha Dar'ya branch and discharged into the southeastern part of the Aral Sea. This similarity in the behavior of the two rivers is apparently not fortuitous, since it is in complete agreement with several other facts verifying that in the Bronze Age the climate was very warm, and thus that the Earth's angular velocity at that time was the lowest during the last 4500 years.

The Hwang Ho deviated to the right (equatorward) during both of the last two cold periods, and it flowed to the south of the Shantung heights until it emptied into the Yellow Sea. Thus, this river periodically shifted its mouth from south to north and vice versa, over a region more than 600 km in length.

The Halhain Gol. In its lower reaches this river flows northwest and discharges into Lake Buyr Nūr, which is joined by the Orchun Gol (Orshun') River to Lake Dalai Nor, situated somewhat to the north. The latter lake in turn is connected via the Mutnaya channel to the Argun' River. In general, this entire system has a northward discharge (Figure 2).

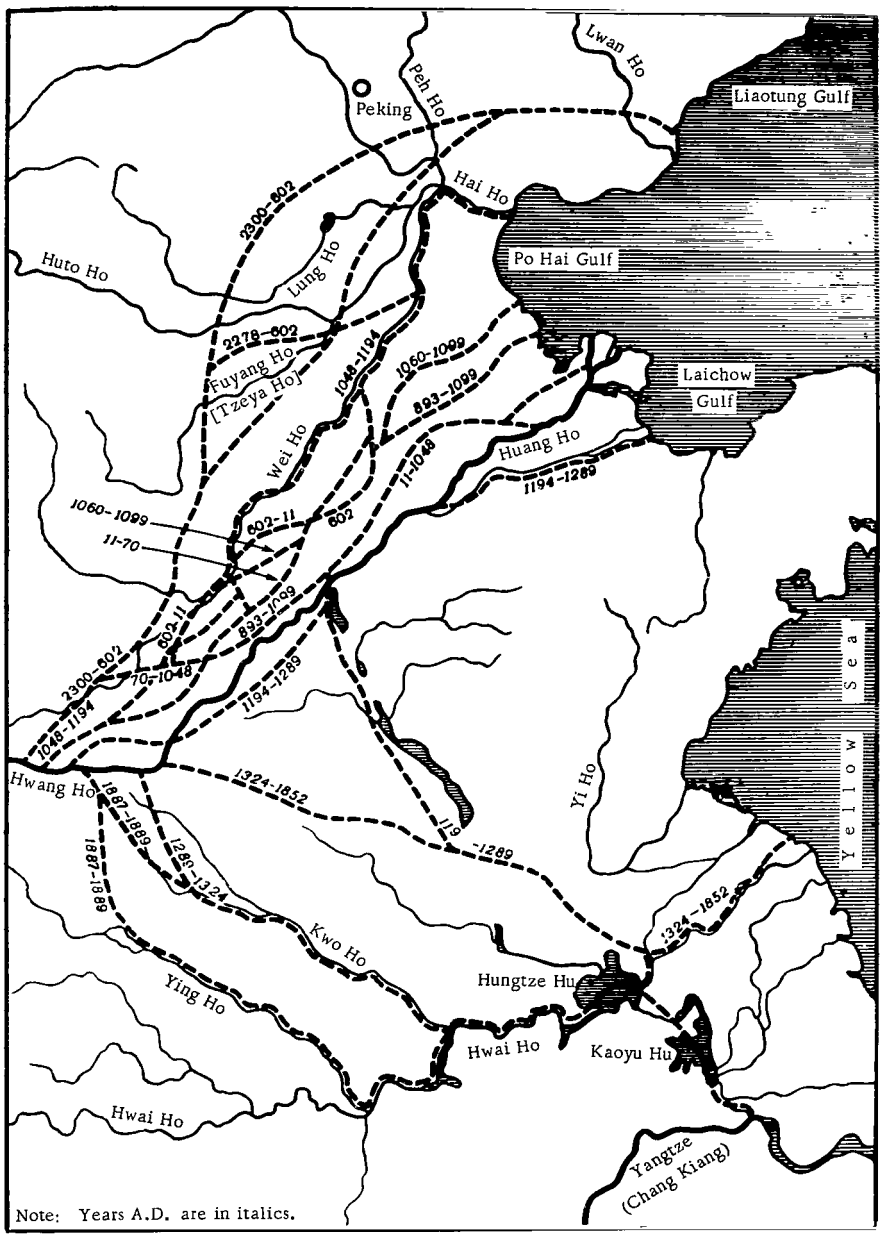


FIGURE 1. Shifts of the Hwang Ho.

Previously, during the third cold period, the Halhain Gol deviated toward the left (equatorward), and flowed entirely into the Buyr Nūr, while its excess water flowed along the Orchun Gol to Dalai Nor. With the onset of the present warm period, the river began to deviate to the right (poleward); as a consequence, the Sharogolchin branch was formed, connecting the Halhain Gol directly to the Orchun Gol. A considerable part of the Halhain Gol then began to flow into Dalai Nor, bypassing Buyr Nūr, and the level of the latter was sharply reduced.

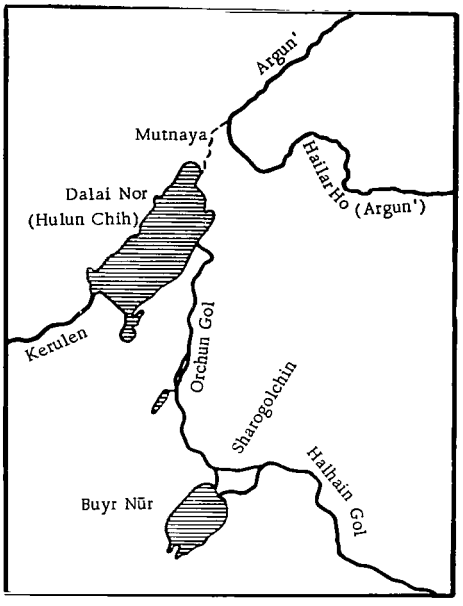


FIGURE 2. Shifts of the Halhain Gol.

"If as time goes by the new Sharogolchin channel becomes scoured out, so that its bed is deeper and its section is greater, the Halhain Gol may flow directly into the Orshun', bypassing Buyr Nūr completely. The latter will then dry up and disappear, and its flat basin will become covered with vegetation (it will become a steppe)... The Orshun' will become the lower reaches of the Halhain Gol, and the two rivers will combine into one. Thus, in front of our very eyes, lakes and rivers are changing, and neither millions nor thousands of years are necessary for it" (Murzaev, 1954, p. 288).

Lake Baikal. Data are available which confirm that the banks of the entire northeastern shore of Lake Baikal are sinking. According to the theory developed in this article, however, a raising of the water level is taking place in the northeastern part of the lake, rather than a sinking of the banks. The level is rising as a result of the poleward shifting of the lake accompanying the decrease in the Earth's centrifugal forces occasioned by the present warming up of the climate. Consequently, it follows that the level of the lake in this region was lower during the previous cold period, and that the lake shifted southward under the effect of the increased centrifugal forces which existed at that time. The discharge from Baikal now takes place in the southern part of the lake. Thus we can assume that the volume of water in the lake during cold periods was less than during warm periods (and that the discharge via the Angara was correspondingly greater or less during these periods).

The Rivers of the Tien Shan. During the present climatic period the channel and delta processes of rivers in the northern and southern Tien Shan Mountains differ greatly from one another. The rivers flowing down the northern slope appear to be in a stage of rejuvenation; they are cutting into their beds and forming deltas which are relatively far away

from the foothills. Rivers on the southern slope, on the other hand, appear to be in a senile stage; their channels are filling up with debris and their deltas are forming close to the foothills. "The indicated differences determine the fundamental, and practically very real, contrast between the structure and regime of the debris cones of the northern and southern slopes of the Tien Shan. The rivers of the northern slope have a more regulated natural regime of discharge . . ." (Kunin, 1960, pp. 142-143). This phenomenon can be explained as a consequence of the decrease in the diurnal-rotation velocity of the Earth during the present warm period.

The Edsin Gol. In its lower reaches this river follows a general northerly course. At its delta it divides into several channels, scattered over a territory as much as 80 km in width. Lakes Gashun Nūr and Sogo Nūr are the bodies of standing water into which the present-day distributaries of this river flow (Figure 3).

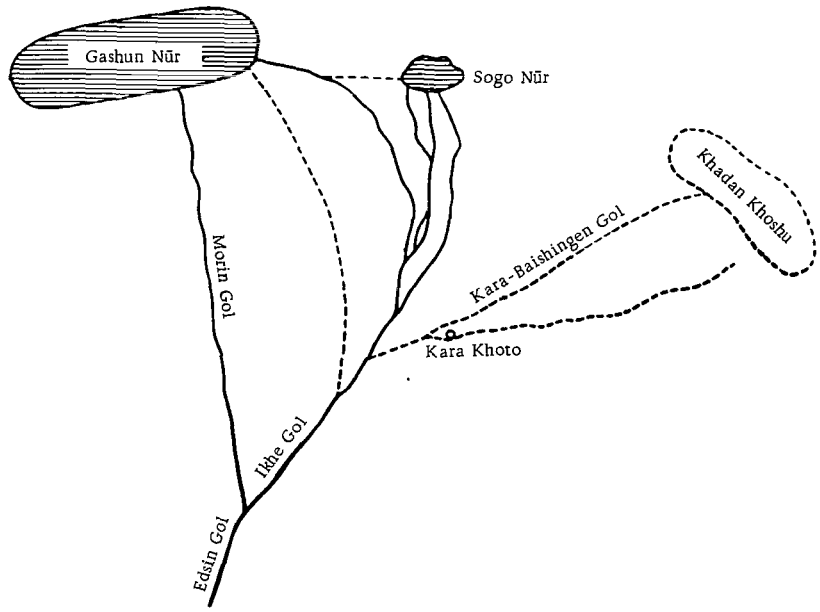


FIGURE 3. Shifts of the Edsin Gol.

During the third cold period (late Middle Ages) the Edsin Gol deviated to the right (equatorward). Consequently, the main discharge was along its right-hand branch, the Kara-Baishingen Gol, following a northeasterly course to the vast Khadan-Khoshu depression. It was at this time that the large medieval city of Kara Khoto existed on the banks of this branch of the river. Lakes Gashun Nūr and Sogo Nūr must presumably have had low levels during this period, if indeed they were supplied with water to any extent at all.

During the third (present) warm period, this river has tended to deviate to the left (poleward). Thus, the discharge of the Edsin Gol gradually became transferred to its left-hand distributaries, the Ikhe Gol and the Morin Gol.

The Morin Gol branch, which has a north-meridional course, and also its standing-water bodies Gashun Nūr, thus now have more water in them. The Ikhe Gol branch, and its standing-water body Sogo Nūr, on the other hand, which are situated more to the south, have gradually become shallower. Finally, the southernmost branch, the Kara-Baishingen Gol, has dried up.

These changes in the river were the main reason for the downfall of the city of Kara Khoto. As pointed out by Murzaev (1956), Kara Khoto and the towns of the Takla Makan clearly went to ruin because the river branches or the main channel of the river changed course, due to natural causes. Uzin (1958) writes that the Edsin Gol previously flowed quite close to Kara Khoto, rather than tens of kilometers away from it as it does now, and that the branches of the river flowed on both sides of the city, giving life to it. However, certain changes took place, causing the river to turn toward the northwest and producing the Sogo Nūr and Gashun Nūr lakes.

The Tarim and Konche Dar'ya Rivers and Lake Lop Nor. In their lower reaches the Tarim and the Konche Dar'ya have a general easterly course and they flow down into the Tarim Basin, to the Lop Nor depression containing Lake Lop Nor (Figure 4). Murzaev (1947, p. 17) considers that the changes in the hydrographic system of the Tarim and the Konche Dar'ya provide a key to the solution of the mystery of Lop Nor, the solution being suggested by nature itself.

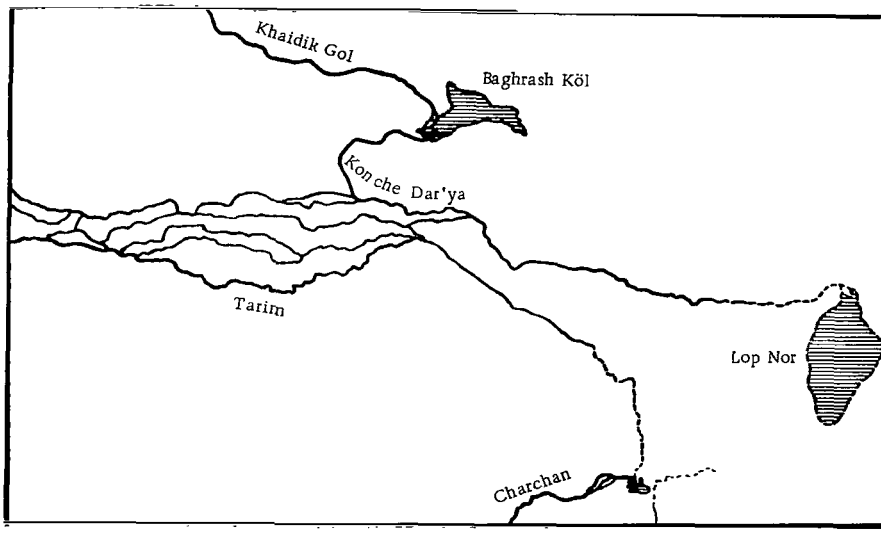


FIGURE 4. Shifts of the Tarim, Konche Dar'ya, and Khaidik Gol.

During the second warm period (early Middle Ages) the Tarim and the Konche Dar'ya deviated to the left (poleward); the two rivers combined to

some extent and discharged along the southern foothills of the Kuruk Tagh range, forming Lake Lop Nor in the northeastern part of the Lop Nor depression. At this time the northern edge of the Takla Makan Desert was more abundantly watered than the southern edge. Apparently this explains the decreased number of settlements in the southern part of the Tarim plain, for example in the vicinity of the Keriya River (Sinitsyn, 1959). It also explains why the east-west trade route went through the northern part of the plain during the early Middle Ages.

In the third cold period (late Middle Ages) the rivers deviated to the right (equatorward). Accordingly, Lake Lop Nor was shifted to the southwest (by about 150 to 200 km), to the foot of the Astin Tagh. The east-west trade route also moved from the northern part of the Tarim plain to the southern part, since conditions there were better at that time.

During the third (present) warm period the Tarim and the Konche Dar'ya show a definite tendency toward leftward (poleward) deviations. The present-day Lake Lop Nor has neither a constant position nor a definite size. Sinitsyn (1959) reports that in the seventh century B.C., according to Chinese sources, Lop Nor was situated in the northern part of the ancient lake basin, at the mouth of the Konche Dar'ya. Then, for a thousand years (or perhaps somewhat less), the lake was located to the south, in the Kara Hoshun region, at the mouth of the Tarim. At the beginning of the present century the southern lake dried up.

Thus, the change in position of the lake in the Lop Nor depression, and also the periodic drying up of this lake, are caused by redistributions of the water along the channels of the Tarim and the Konche Dar'ya. Present-day observations (see "Zarubezhnaya Azia" [Non-Soviet Asia], edited by B. F. Dobrynin and E. M. Murzaev, 1956, p. 269) indicate that now one branch of the Tarim joins with the Konche Dar'ya to flow along the ancient Kum Dar'ya channel; after 250 km this water flows into Lop Nor, and as a result of this the lake has moved northward. The studies of Chao and Chao (1961, p. 88) also show that at present the channels of the Tarim have a tendency to migrate toward the north.

The Khaidik Gol and Lake Baghrash Köl. In its lower reaches the Khaidik Gol follows a southeasterly course. It discharges into Lake Baghrash Köl, which is located in the Karashahr basin (see Figure 4). The surplus water from Baghrash Köl flows into the Tarim basin via the Konche Dar'ya, which exits from the southwestern part of the lake. Thus, Baghrash Köl is part of a circulating system: it is fed by a surface and subsurface flow coming in general from the north, and its surplus flows out southward via the Konche Dar'ya. Somewhat downstream from the city of Karashahr, the present-day delta of the Khaidik Gol begins. Here the river divides into two branches, the left one flowing directly into Baghrash Köl, and the right one, which actually bypasses the lake, flowing through a system of small overflow lakes to the Konche Dar'ya.

During the third cold period (late Middle Ages), the Khaidik Gol deviated to the right (equatorward) and flowed southward, bypassing what is now Baghrash Köl, directly to the Konche Dar'ya. The lake then had little water in it, since it was fed principally by the subsurface flow and by the small rivers to the north of it. The total discharge in the direction of the Tarim basin was relatively large.

During the third (present) warm period, the river tends to deviate to the left (poleward). The left branch has developed and now carries the

main bulk of the Khaidik Gol to Lake Baghrash Köl, after which the flow is along the Konche Dar'ya to the Tarim basin. The level of Baghrash Köl is at present rising.

As Kuznetsov and Murzaev (1960) have pointed out, Roborovskii and Kozlov (1896) made no mention of the presence of the left branch of the Khaidik Gol, and they did not indicate it on their map. Apparently, this branch formed after these travelers visited the lake. The observations of Kozlov, Kuznetsov, and Murzaev make it clear that during the last 70 or 80 years the channel of the Khaidik Gol has been shifting toward the northeast in the vicinity of its mouth. The same tendency is observed further upstream, after the river has debouched from the mountains and entered the plain.

The Manass River and Lakes Ayran Köl and Ikhe Khak. In its lower reaches the Manass follows a northwesterly course. It discharges into an inland basin located in the western part of the Dzhungarian plain, near the southeastern foothills of the Chingiz Mountains. The basin extends toward the northeast and is divided into two parts, a southwestern part containing the Ayran Köl solonchak [salt marsh] and a northeastern part containing the Ikhe Khak solonchak.

"The Manass River, which supplies the present-day lake, divides into a number of distributaries when it enters the basin. Some of these flow into the western half, to the Ayran Kol solonchak, while the others go eastward, to the Ikhe Khak solonchak. Therefore, the lake actually does not have a definite location, and it may be in either the Ayran Köl region or the Ikhe Khak region, depending on the distribution of water in its distributary channels . . . " (Sinitsyn, 1959).

During the third cold period (late Middle Ages), the Manass deviated to the left (equatorward). At this time it discharged into the Ayran Kol solonchak, the present site of the lake. The right-hand distributaries were then insufficiently supplied with water and the Ikhe Khak depression became a solonchak.

During the third (present) warm period, the river has a tendency to deviate to the right (poleward). Consequently, the Ikhe Khak depression has become supplied with water and Lake Ayran Köl has dried up.

Murzaev (1939) cites the Manass River as an example of a recent migration of distributary channels. This river used to discharge into Lake Ayran Köl, which is now dry. The main channel of the present Manass delta shifted to the northeast and formed the large but shallow and salty Lake Ikhe Khak, in the ancient lake-solonchak basin. Certain facts make it clear that this is not the first time that the Manass has migrated toward the northeast.

The Ili River and Lake Balkhash. In its lower reaches the Ili flows northwest, until finally it discharges into Lake Balkhash. At the beginning of its delta the river divides into two large distributary systems: the Ili system proper on the left, and the Bakanas system on the right. At present the flow is along the Ili system of distributaries, the largest of which are the Topar (left), the Ili (middle), and the Dzhideli (right).

During the third cold period (late Middle Ages) the Ili deviated to the left (equatorward). At this time Lake Balkhash also moved toward the south. The main flow of the Ili was then along the left branch, the Topar, while part of the flow was along the middle branch, the Ili. The level of

Balkhash was relatively low in the northeastern part of the lake and relatively high in the southwestern part. During the third (present) warm period the river tends to deviate to the right (poleward). Therefore the right distributary, the Dzhideli, is now quite developed and well supplied with water, whereas in the left distributary, the Topar, the flow has practically stopped. The level of Balkhash has become higher in the northeastern part of the lake and lower in the southwestern part.

"For 4 or 5 km of their upper reaches, the Topars traverse the floodplain of the Ili, a plain which was formed when the river channel shifted to the right. In the forties of this century, there was already more water in the Dzhideli system than in the Ili channel, and at present the main part of the flow of the Ili River is along this system. Moreover, the stream velocity in the upper part of the Dzhideli branch is now considerably greater than that in the Ili. Consequently, the Dzhideli branch is able to transfer efficiently the sediment entering it, and in addition it is able to develop its channel. At the same time, some of the sediment is being deposited in the regions where the Topar and Ili branches flow into the lake, due to the sharply reduced stream velocity there; thus, conditions for the intake of water into these systems are becoming less favorable" (Khaidarov, 1960, pp. 269-270).

It should be noted that the Bakanas branches were formerly the channels of the Ili River. As early as 1902, L. S. Berg pointed out that a number of large and small irrigation ditches (at present dry) branch out from the banks of the Bakanas branches, and that traces of ancient plowed fields are evident everywhere, providing definite evidence that an agricultural settlement existed there at some time.

Unfortunately, however, these traces cannot be dated accurately. Thus, the regular correlation between climatic changes and river migrations established above by us is the only real basis for assuming that the Bakanas channels were "active" during the warm periods (Bronze Age and early Middle Ages).

"... a study of the banks reveals that the southern shores of Lake Balkhash are gradually but continually being filled in with fluvial deposits, and that at the same time the northern shores of the lake are being inundated. Places where there were inlets along the south shore 30 or 50 years ago have become dry, whereas the northern banks have an appearance typical of places where the land is being washed away and the water level is rising. On a 1903 map the Boichabyl area was shown as an island, whereas now it has become a peninsula. The inlets at the southwestern end of the lake have dried up completely during the last 15 or 20 years. Thus we see that Lake Balkhash is actually a wandering lake, and is very similar in this respect to Lake Lop Nor in Central Asia" (Fedorovich, 1954).

The Nura River and Lakes Tengiz and Kurgal'dzhin. In its middle reaches the Nura flows northward. Not far from Akmolinsk the river makes a sharp bend toward the southwest and forms Lakes Tengiz and Kurgal'dzhin, which are situated in the desert-steppe region of central Kazakhstan (Figure 5).

During the third cold period (late Middle Ages) the Nura deviated toward the left (equatorward), and its entire flow went through Lakes Tengiz and Kurgal'dzhin; at this time the level of the lakes was high. As Popolzin (1960) has pointed out, even in comparatively recent times Lake Kurgal'dzhin was a vast body of water with a large open-water surface.

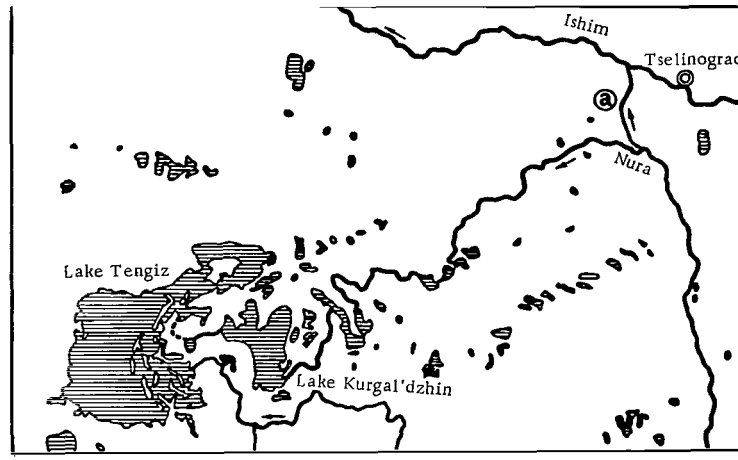


FIGURE 5. Migrations of the Nura.

During the third (present) warm period, on the other hand, the river tends to deviate to the right (poleward). Consequently, at the northernmost point of the large bend, some of the water of the Nura breaks through and flows, along the shallow depression between the Ishim and the Nura, into the Ishim basin. This has led to a reduced supply of water to Lakes Tengiz and Kurgal'dzhin, and the latter are rapidly drying up.

"The lakes in the Tengiz-Kurgal'dzhin group are water bodies which are in a state of gradual drying up. This drying-up process became especially intensified after some of the water of the Nura broke through to flow into the Ishim River, causing a certain reduction of the level of the lakes" (Popolzin, 1960, p. 84).

The Indus. This river has a southwesterly course in its lower reaches and discharges into the Arabian Sea. During the third cold period (late Middle Ages) the Indus deviated to the left (equatorward), and its course was nearly south-meridional. During the present period of climatic warming the Indus tends to deviate to the right (poleward). This conclusion is corroborated by the findings of Machaček (1961), who decided that the Indus channel is shifting westward during the present epoch.

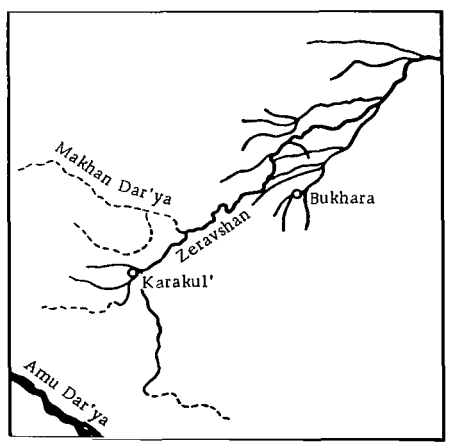


FIGURE 6. Migrations of the Zeravshan.

The Zeravshan. In its lower reaches this river follows a southwesterly course. After irrigating the vast Bukhara oasis, the Zeravshan goes dry, coming to within about 20 km of the Amu Dar'ya (Figure 6).

During the first warm period (Bronze Age) the river deviated

to the right (poleward). The flow was then along the right branch, the Makhan Dar'ya, which flowed toward the northwest, as far as the Uch Bash hills. At that time a large delta existed there, and a huge strip of land was under water. Primitive settlements grew up along the Makhan Dar'ya and in the region of its delta, the settlers being cattle breeders and farmers.

During the second cold period (antiquity), the Zeravshan deviated to the left (equatorward). The flow along the Makhan Dar'ya then ceased and the settlements which depended upon this water became deserted. The whole Makhan Dar'ya delta became uninhabitable at this time.

During the second warm period (early Middle Ages), the river once again deviated to the right (northward). Accordingly, the territory to the west of Bukhara became watered again. One of the many remains dating from this time is the Varakhsha fortress (Shishkin, 1940, 1950).

Dzens-Litovskii (1936, p. 22) assumes that in the sixth century A.D. the northern part of what is now the cultivated strip of the Bukhara oasis was a swampy plain, the so-called Sufioni marshes.

During the third cold period (late Middle Ages), the Zeravshan deviated to the left (southward). Accordingly, the land in the vicinity of the Varakhsha fortress became deserted, while the left bank of the Zeravshan became well watered. Here, beginning at Pendzhikent and continuing further downstream, an effective irrigation system was constructed and continued to function for a long time (particularly noteworthy were the Dargan canal and, to the south of it, the Manas canal).

The whole left bank of the river was densely populated at this time, and these medieval settlers left behind a great many monuments of various kinds. The southern part of the delta itself (the Karakul' oasis) was also well watered. In the time of Genghis Khan, this district was a vast stretch of lakes and swamps.

During the third (present) warm period, the Zeravshan tends to deviate to the right (poleward). The irrigation system based on the left-bank canals is thus now being disrupted. According to the data of Arandarenko (1889), the Manas irrigation ditch ceased operating sometime after the Timurid period. The Tyue-Tartar, Mirza-Aryk, and Polvan canals, which branch out from the right bank of the river, were maintained at a constant water level with almost no effort at all. The operation of dams and maintenance of the water level in the left-bank canals (the Sarazm-Any-Kazan and Ayaz-Abat canals), on the other hand, turned out to be quite difficult for the agricultural population. The southern part of the delta became dry, the irrigated farmlands went into disuse, and the region became deserted. For example, along the Taikyr River, the last terminal channel of the Zeravshan, there are enormous areas of cultivated land which stand neglected, and abandoned mazars [a kind of holy grave] and the ruins of adobe kibitkas [rude huts] are to be seen (Dzens-Litovskii, 1936, p. 23).

The Syr Dar'ya. In its lower reaches this river follows a northwesterly course, after which it empties into the northeastern part of the Aral Sea (Figure 7). During each of the last two cold periods (antiquity and the late Middle Ages), the Syr Dar'ya deviated to the left (equatorward) and followed the Kuvan Dar'ya and Zhana Dar'ya channels to the southeastern bays of the Aral Sea; at these times it inundated the Akcha Dar'ya delta of the Amu Dar'ya intermittently. Tolstov (1960) is also of the opinion that in

ancient times the southernmost branch of the Syr Dar'ya (the Zhana Dar'ya) was the main channel of the river. During the last two warm periods (the Middle Ages and the present), on the other hand, the deviation was to the right (poleward), and accordingly the Kuvan Dar'ya and Zhana Dar'ya channels dried up.

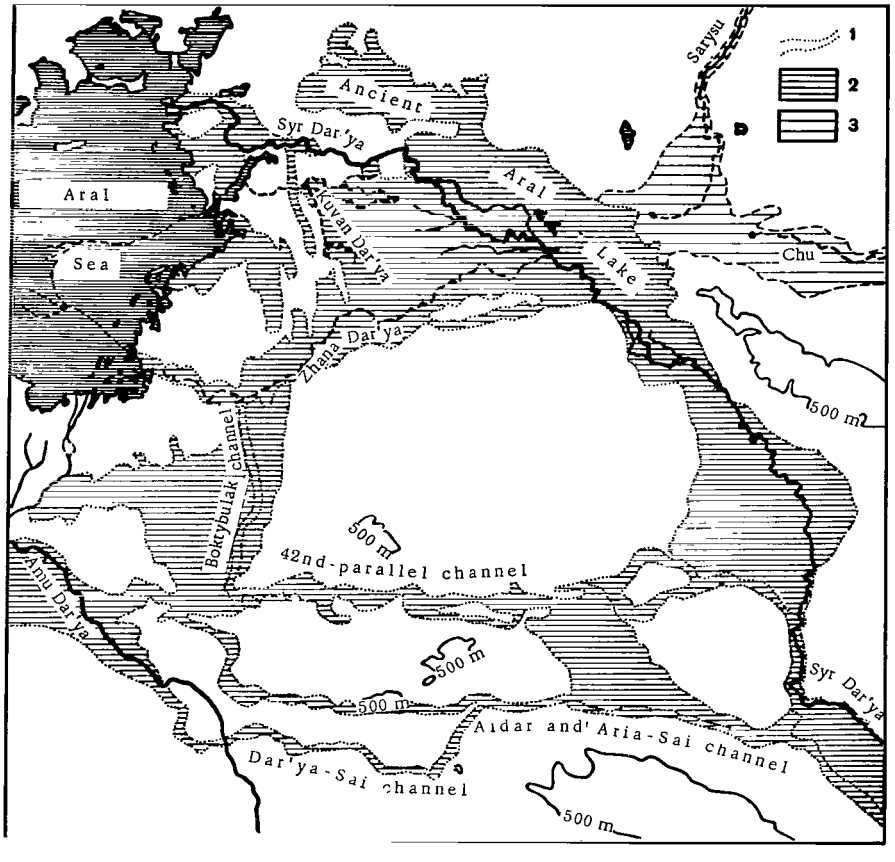


FIGURE 7. Migrations of the Syr Dar'ya: 1) ancient channels of the Syr Dar'ya; 2) region of fluvial deposits of the Syr Dar'ya, and of its former channels and lakes; 3) fluvial-deposit region of ancient tributaries.

This sequence of the migrations of the river is borne out by many data, in particular by the findings of archaeological-geomorphological studies. For example, it has been established that during the cold periods the Kuran Dar'ya and Zhana Dar'ya deltas, right down to the Akcha Dar'ya delta of the Amu Dar'ya were densely populated, as in ancient times, when the so-called Kokcha-Tengiz culture was widespread in this region, and in the late Middle Ages, from the twelfth and thirteenth centuries on.

The main occupation of the people inhabiting these areas was irrigation farming, which could only have been possible using the distributary waters

of the Syr Dar'ya. This indicates that in ancient times and in the late Middle Ages the Amu Dar'ya deviated to the south. However, the more the cold phase of the climatic cycle gave way to the succeeding warm phase, the less water there was in the left-bank distributaries of the Syr Dar'ya and the more the channels became filled up with deposits.

In spite of the increased efforts of its users to adapt the irrigation system to the new hydrological conditions, due to the lack of water the system was no longer able to perform its function, namely to irrigate the fields. Thus farming declined and the whole region became desolate. Numerous remains of ancient towns and settlements, as well as of irrigation structures, all dating from antiquity and from the late Middle Ages, attest to what took place in this region. The fact that there are no such remains from the warm period of the early Middle Ages on the Kuvan Dar'ya and Zhana Dar'ya deltas, moreover, is further evidence of this.

The tendency of the Syr Dar'ya to migrate during the present warm period is verified by the direct observations of various investigators (for example, Bogdanov (1882)). The northward deviation of the Amu Dar'ya during this period was accompanied by a deviation of the Syr Dar'ya in the same direction. The Sarysu and the Chu gradually became separated from the Syr Dar'ya, and the Yany Dar'ya and Zhana Dar'ya became overgrown. The Syr Dar'ya found a new course along the Kuvan Dar'ya, but then it abandoned this course as well and found its present channel. As a consequence, the Yany Dar'ya and Kuvan Dar'ya dried up. It should be recalled that Myshkin's map for the year 1831 showed the Syr Dar'ya discharging into the Aral Sea via three branches (the Zhana Dar'ya, the Kuvan Dar'ya, and the Syr Dar'ya).

Recently, the channels on the right side of the Syr Dar'ya have developed considerably. For example, the Kara Uzyak, which was formed at the site of the extensive floods at the end of the last century, carried only 10% of the discharge of the Syr Dar'ya in 1925, whereas at present it carries 40%. This development of the channel, moreover, is continuing.

Borovskii and Pogrebenskii (1958) think that the bulk of the water of the river is in the process of shifting over from the Syr Dar'ya channel to the new, growing Kara Uzyak channel. In connection with this shift to the Kara Uzyak, it may be assumed that the Dzhaman Dar'ya, the main channel of the Syr Dar'ya, will become silted up at its beginning.

The Kara Uzyak and Kok Su distributaries will undergo an intensive development, deepening and widening their channels and thereby reinforcing the discharge to the right. This shifting of the distributaries northward may also continue further, as far as the Kara Kemir bench.

The Amu Dar'ya. In its lower reaches this river flows northwest and discharges into the Aral Sea (Figure 8). It is a known fact that the Amu Dar'ya has repeatedly and abruptly changed course and migrated over a vast territory in the western plains of Central Asia, and that these plains were formed primarily by the alluvial deposits of this great river.

On the basis of the correlation between the cyclical fluctuations of the climate and the planet-wide rearrangements of the drainage

system, it is possible to draw up the following approximate plan of the successive shifts in the course of the Amu Dar'ya during the Quaternary period.*

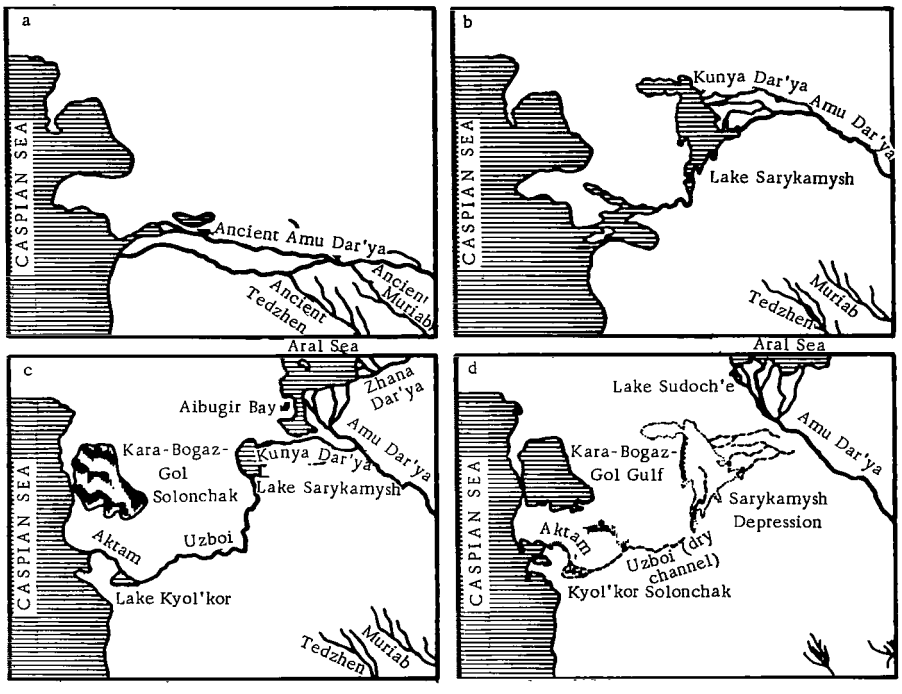


FIGURE 8. Migrations of the Amu Dar'ya.

* With respect to the Quaternary as a whole, the "behavior" of rivers flowing in different directions, such as the Mississippi and the Rhine (which flow southward and northward, respectively), is significant. During each glacial period the rate of flow of the Mississippi, and thus the transporting capacity of the river as well, increased. As a result deep erosion took place; the river cut into its bed and carried sediment far out to sea. The water table was reduced accordingly, and conditions were such that a more or less thick soil cover was formed.

During these same periods, on the other hand, the flow rate of the Rhine decreased. The margin of its delta deposits moved inland, and its valley filled up with sediments and became swampy. During each of the warm interglacial periods the channel processes of these two rivers were just the opposite of those described. For example, at present the Rhine is going through a stage of rejuvenation, while the Mississippi is in a senile stage.

During the Quaternary, channel processes in the Mississippi and the Rhine took place synchronously with and in rhythm with the climatic fluctuations. These processes were, however, opposite for the two rivers: when one was in a stage of rejuvenation, the other was in a stage of senility. This regularity can be explained satisfactorily in terms of a climatically induced irregularity of the Earth's diurnal rotation, this irregularity being more pronounced during the glacial periods than during the interglacial periods.

The period of Dnieper glaciation was characterized by an enormous accumulation of solid moisture in the high latitudes. Accordingly, the Earth's diurnal velocity was relatively high, and the global drainage system shifted equatorward under the influence of the centrifugal forces. The Amu Dar'ya also shifted in this direction at that time. Pressing on to the foot of the Kopet Dagh, it flowed into the southwestern depressions of the Aral-Caspian plain and filled them up with alluvial deposits (see Figure 8a).

The period of Dnieper glaciation was succeeded by a warm interglacial period. The solid moisture in the high latitudes then turned into liquid and part of it was transported to the low latitudes. As a result, the diurnal rotation of the Earth slowed down and the centrifugal forces were reduced accordingly. The drainage system responded to the new rotational regime of the Earth by shifting toward the poles. During this epoch the Amu Dar'ya deviated to the right (northward), and the depressions located in the northwestern part of the Aral-Caspian plain began to receive its discharge. At that time it flowed into these depressions and filled them up with alluvial deposits (Figure 8d).

The warm interglacial period gave way in turn to a new wave of climatic cooling. However, the glaciation at this time was on a smaller scale than during the preceding glacial period. Consequently, the equatorward shift of the global drainage system was also less.

The Amu Dar'ya then deviated to the left and flowed first into Lake Sarykamysh and afterwards along the Uzboi to the Caspian Sea (Figures 8b, 8c); at this time the central and southwestern depressions of the Aral-Caspian plain were watered and filled in with sediments. Thus, the river then occupied an intermediate position between the following two extremes: a north-meridional course (corresponding to the warm interglacial period) which lay approximately along the Akcha Dar'ya channel, and a latitudinal course (corresponding to the period of the Dnieper maximum of climatic cooling) along the foothills of the Kopet Dagh.

During the postglacial period, and in particular during the last 4500 years, the Amu Dar'ya also deviated southward whenever there was a time of climatic cooling (at the end of the Neolithic, in antiquity, and in the late Middle Ages). Thus the region around the Sarykamysh delta became watered and to some extent the Sarykamysh basin itself; the water level in the latter sometimes became so high that the excess overflowed into the Uzboi and on into the Caspian. During each of the three warm periods (Bronze Age, early Middle Ages, and the present), on the other hand, the river deviated northward. As a consequence, its left bank (the Sarykamysh delta) dried up and its right bank received more water.

The foregoing conclusions are borne out by historical-archaeological and geomorphological studies carried out for the region in question; such studies have been made by Gulyamov, Tolstov, Kes', Zhdanko, Itina, Trombachev, Lents, and others.

Along the Uzboi Bronze-Age remains are found considerably more rarely than Neolithic remains, whereas on the Akcha Dar'ya delta there were more Bronze-Age settlements. This indicates that during the Bronze Age there was much less water in the Uzboi, and that most of the water flowed out to the north, to the Aral Sea, or else along the Akcha Dar'ya distributaries. In ancient times, however, the Akcha Dar'ya ceased to

exist, as indicated by the canals built at this time, which led directly from the Amu Dar'ya (in its present course). All the main left-bank distributaries of the Sarykamysh delta, on the other hand, were active at this time. Most of the water of the Amu Dar'ya flowed via the old Daudan stream into the Sarykamysh basin, and then out along the Uzboi (some of the water may even have bypassed the basin).

The abundant supply of water which resulted from the southward deviation of the Amu Dar'ya enabled the ancient inhabitants of Khorezm to construct a magnificent irrigation system within the vast environs of the Sarykamysh delta. In this region irrigation farming ensured a flourishing economy at the time. In the early Middle Ages, however, with the onset of the next warm period, the river deviated to the right and the region around the Sarykamysh delta was no longer supplied with water.

The inhabitants of Khorezm then made strenuous efforts to prolong the operation of the irrigation system (by deepening the canals, by transferring the main ducts upstream, by introducing hoisting wheels to raise the water, etc.). However, nevertheless, most of the irrigated regions finally had to be abandoned, and the settlers moved either to distant places where there was water or else to the right bank of the Amu Dar'ya, where conditions were better at that time. A new irrigation system was then constructed, which included, among others, the large Kurder canal. During this period the Sarykamysh channel of the Amu Dar'ya, Lake Sarykamysh, and the Uzboi River did not exist. The land in the Sarykamysh delta became well watered again only with the onset of the next cold period (late Middle Ages). "Following the catastrophic curtailment of irrigation in the fourth to eighth centuries, the irrigation system in the territory of the Sarykamysh delta was reconstructed and expanded again, but it did not reach anywhere near the scale of the ancient system" (Tolstov, Kes', et al., 1960).

During the present warm period the Amu Dar'ya once more has a tendency to deviate to the right. In the middle of the last century this led to, first, a catastrophic flooding of the rich farmlands in the Kushkan Tau hills, which were inhabited by Karakalpaks, and, second, to a complete lack of water in the Khan Abad region, situated more to the west. In an attempt to retain the disappearing water, the inhabitants of northwestern Khorezm constructed dams, but to no avail. The Kungrad and Shomonai farming regions were destined to be abandoned.

As the Amu Dar'ya shifts to the right, it appears to ascend an inclined plane. The great height of the right bank is indicative of the fact that this bank is being undercut by the river. During the last hundred years the Amu Dar'ya has moved about 10 km to the east in the Khozaraps-Urgench region. The rightward deviation of the river is in evidence all along the lower reaches of the Amu Dar'ya; this has made it necessary to extend the existing inlet channels to the irrigation ditches or to dig new ones. The periodic migrations of the river have inevitably entailed a resettling of the local population, whose lives and activities depended to some extent or other upon the water of the Amu Dar'ya.

The Aral Sea. This body of water is located in the southeastern part of the Aral-Caspian depression. Its water supply depends on the surface flow and subsurface flow into the area.

However, the amount of water in the Aral basin is governed not only by the volume of the Amu Dar'ya, the Syr Dar'ya, and the subsurface

water, but also by the direction of flow of these. As we have pointed out above, the Amu and Syr Dar'yas, and also the subsurface water, have a tendency to shift equatorward during periods of cold climate and a tendency to shift poleward during periods of warm climate. Obviously, these successive shifts of the surface and subsurface water in the basins of the two rivers will have a direct effect on the level of the Aral Sea: in cold periods it will be lower, and in warm periods it will be higher.

Very few factual data are available on the levels of the Aral Sea during ancient times. For various reasons, however, many investigators have concluded that this level underwent repeated, substantial variations. Fedorovich (1954) thinks that the small Paleo-Aral Lake which came into being during the Apsheron period did not exist throughout the entire Quaternary. Alenitsyn (1874), who discovered some winter-hardy animals native to a dry sandy desert on the islands of the Aral, concluded that they migrated there when the islands were joined to the desert by dry land. This could only have taken place at a time when the Aral, supplied just by the Syr Dar'ya, was a small, shallow lake, in comparison with the present-day sea. "Whereas there are numerous indications that the level of this lake was very high in the preceding period, certain other facts show that there was also a time when the Aral did not fill up its entire basin. Its level and its area have become alternately greater and smaller ever since men began to dwell on its shores" (Reclus, 1898, p. 363).

During the first warm period the level of the Aral Sea was high. Yanshin (1953) assumes that the transgression of the Aral Sea which deposited the terrace with Gardium Edule L. shells was most likely related to the period when the climate of Turan was the most arid. This transgression may have taken place at the time of the Kel'teminar culture, since it occurred in the third millenium B. C. Consequently, this transgression is linked with a period when there was a general rearrangement (a poleward shift) of the drainage system. In particular, at this time the Amu Dar'ya made its maximum rightward deviation and flowed along the Akcha Dar'ya channel. This was the main reason why the Aral basin was then supplied with water.

During the second cold period (antiquity) the level of the Aral Sea was low. Tolstov and Kes', on the other hand, assume that at this time (middle of first millenium B. C.) there took place a transgression of the Aral Sea which raised the level to 3.5 or 4 meters above the present level. Their assumption was based on the geomorphological features of the southeastern part of the Aral Sea, on the distribution of sea shells there, and on the fact that Iron-Age sites have been found on its shores. However, the assumption of Tolstov and Kes' is contradicted by the following statement of Kes' (1958, p. 95): "... The Aral Sea became a large basin only after the Amu Dar'ya and Syr Dar'ya began to discharge completely into the vast Aral depression. Both of these rivers have highly variable courses: during the most recent stages of geological history the rivers migrated repeatedly, sometimes discharging into the Aral Sea and sometimes turning aside and flowing, partially or completely, into other Central-Asian depressions. Whenever the Amu Dar'ya turned aside for any long or short period (for example, toward Sarykamysh), the level of the Aral Sea dropped sharply".

Let us also quote the following statement of Reclus (1898, p. 363): "The Aral Sea depends entirely on the extent to which it is supplied by

the two rivers discharging into it. If the Amu Dar'ya and Syr Dar'ya move away from the Aral depression and flow into the Caspian instead, the "Sea of Khorezm" will inevitably become shallow and then dry up after some years. However, as we have seen, the Amu Dar'ya has already deserted the Aral twice during historical times, and in addition one branch of the Syr Dar'ya once flowed into the Caspian via the Oxus (Amu Dar'ya) channel". Thus, in antiquity, when all the tributaries of the Sarykamysh delta were flowing, the level of the Aral Sea could not have been very high. Most likely, this body of water was then just a small steppe lake.

Now let us consider the presence of Iron-Age sites on the shore of the ancient sea, the level of which was 3.5 to 4 meters higher than at present. We can assume that the settlements and the shore itself developed at different periods, since the shoreland had to form before dwellings could be erected on it. During antiquity people were probably forced to settle in elevated places, since at that time the Syr Dar'ya deviated to the left and abundantly watered the territory around the southeastern part of the Aral Sea. Thus, according to Tolstov, this entire region was a kind of "Central-Asian Venice" during ancient times.

It is noteworthy that ancient writers make no reference at all to the Aral Sea. Apropos of this, Reclus (1898) states: "It is difficult to explain how such a vast water area, at present almost as extensive as the Aegean, could have been completely unknown to the ancients, if it had the same dimensions then as it does now. Greek rulers governed the countries between Persia and the large mountain ranges of Central Asia for several centuries. Moreover, Greek-speaking traders and military leaders crossed the Oxus and Jaxartes Rivers, but none of them made any mention of a second sea lying to the east of the Hyrcanian (Caspian) Sea."

However, then came the next warm period, with maximum climatic warming in approximately the sixth century A.D., and the Amu Dar'ya and Syr Dar'ya gradually deviated to the right (poleward). Accordingly, the flow of water into the Aral depression increased, and a body of water was formed there which was large enough to command the attention of the people of that time. In actual fact, writers of the early Middle Ages stopped referring to the discharge of the Amu Dar'ya and Syr Dar'ya into the Caspian. Instead, they reported that the two rivers flowed into the Aral Sea. These writers were acquainted with the Aral; they drew it on their maps and discussed navigation on it.

During the third cold period (late Middle Ages) the water-supply situation for the Aral Sea was more or less the same as during the second cold period (antiquity). The Amu Dar'ya and Syr Dar'ya deviated southward, less water flowed into the Aral basin, and if there was a lake in the basin it was small. Reports concerning the Aral once again ceased (not a single European traveler makes any reference to it). Then, with the onset of the present warm period, the two Dar'yas tended to shift to the north again. Accordingly, the flow into the Aral increased and the level rose.

Lake Sarykamysh. This lake lies between the Caspian and Aral Seas, and its geographical position determines the nature of its water supply. Optimum conditions for filling the Sarykamysh basin with water exist when the centrifugal forces of the Earth's rotation are not so great that the Amu Dar'ya, the Syr Dar'ya, and the other rivers to the east and northeast of the basin deviate too far southward. When the rivers deviate to the south,

they bypass the Sarykamysh basin and discharge into the Caspian; this was the case, for instance, during the period of Dnieper glaciation (see Figure 8a). However, the centrifugal forces cannot be so small that the rivers deviate too much to the north either, since then they will bypass the Sarykamysh basin and flow into the Aral; this is the situation during the present warm period (see Figure 8d). Optimum conditions evidently existed during the Würm glacial period and during the long periods of climatic cooling which occurred in postglacial times (Figures 8b and 8c).

The foregoing general considerations are confirmed by the following conclusions of Shnitnikov (1959):

1. Three times during the last 4000 to 4500 years the Sarykamysh basin was filled up by the Amu Dar'ya, and during these periods flow took place along the Uzboi channel.

2. During the time interval between the second and third fillings of the basin (that is, in the first millenium A.D.), Lake Sarykamysh dried up completely. Moreover, there is definite evidence that the basin was dry in the period between the first and second fillings as well. At present, too, the basin is dry.

3. All three periods during which the Amu Dar'ya filled the Sarykamysh basin coincide in time with cool, wet phases in the great rhythmic wetness cycles for the continents of the Northern Hemisphere. The times when the Sarykamysh basin was dry and there was no flow along the Uzboi channel, on the other hand, coincided with the long dry phases of the rhythmic wetness cycles.

The Atrek. In its lower reaches this river has in general a westerly course. The water is entirely used up for irrigation and only reaches the Caspian at the time of floods.

During the first warm period (Bronze Age) the Atrek deviated to the right (northward) and watered the so-called Messerian plain. At this time the archaic-Dakhistan culture existed on the plain. V.M. Masson (1954) suggests that the archaic-Dakhistan culture be dated to the first third of the first millenium B.C. and to some unspecified part of the second half of the second millenium B.C.

During the second cold period (antiquity) the river deviated to the left (southward). Consequently, the Messerian plain dried up, the irrigation system stopped functioning, and the archaic-Dakhistan culture went into a decline.

During the second warm period (early Middle Ages) the Atrek deviated to the right (poleward). The Messerian plain then became well watered once more, and settlers began to come there. It was at this time that the so-called Ephtalito-Turkic culture reached its apex (VI-VIII centuries A.D.).

During the third cold period (late Middle Ages) the river deviated to the left, and the Messerian plain became a desert. According to the data of Masson, settled life in the oasis died out completely in the fifteenth century.

During the present warm period the Atrek tends to deviate to the right (poleward). Murzaev (1957) notes that with the approach to the delta the banks gradually recede and become lower. In this region the Atrek flows through lowlands and turns vast areas into swamps; it divides into branches and its channel shifts northward. Thus, Hasan-Kuli Bay is at present being filled up with deposits from the Atrek, in spite of the fact that the Caspian Sea has a low level, which is favorable for downcutting of the river bed.

The Black and Caspian Seas. Studies of fluctuations in the levels of the Black and Caspian Seas during the Holocene led Fedorov and Skiba (1960) to the following conclusions. Transgressions of the Black Sea (the Neoeuxine, Nymphaic,* and Recent transgressions, at any rate) coincide with dry, warm periods, whereas regressions coincide with wet, cool periods. Transgressions of the Caspian (Neo-Caspian, at most Neo-Caspian and late Neo-Caspian), on the other hand, take place during wet, cool periods, while regressions of the Caspian correspond to dry, warm periods. Thus, transgressions of the Black Sea correspond to regressions of the Caspian, and vice versa.

In connection with the foregoing conclusions of Fedorov and Skiba, we should add the following. We decided long ago that the fluctuations in the levels of the Azov-Black and Caspian Seas over the centuries (at least during the last 4500 years) were asynchronous, and that these fluctuations correlate very closely with Shnitnikov's curve for the long-term variability of the wetness of the Northern Hemisphere during this same period. We reported this conclusion in April 1960 at a meeting of the Geology Section of the Conference on the Caspian Problem, held by the USSR Academy of Sciences in Moscow. At this conference it was noted, in particular, that it is impossible to explain completely all the observed regularities in the level fluctuations of the Azov-Black and Caspian Seas in terms of solely eustatic variations (for the Azov-Black Sea basin) and in terms of variations in the precipitation-evaporation balance (for the Caspian). Moreover, it is impossible to explain these regularities even if we take into account tectonic movements. For example, how can we explain the fact that during the present period the level of the Azov-Black Sea water is rising twice or three times as fast as the level in the ocean at the same latitudes? Also, how is it possible to account for the difference between the long-term fluctuations in the level of the Caspian in the south (around Baku) and the fluctuations in the north (around Astrakhan)?

A satisfactory explanation of all the observed regularities in the level variations of these bodies is possible only if we take into account the long-period fluctuations (over the centuries) in the diurnal-rotation regime of the Earth, produced [as noted above] by the rearrangements of the water mass on the Earth's surface which accompany climatic fluctuations. The observed regularities in the level fluctuations of these water bodies are probably, to a large extent, a particular manifestation of a more general regularity in the evolution of the Earth. This more general variation is the periodic (synchronous with climatic fluctuations, and thus with fluctuations in the Earth's diurnal-rotation regime) rearrangement of the drainage system on a planet-wide scale, in which the rivers and water bodies are oriented (shifted) sometimes poleward and sometimes equatorward.

It is important to note the following: numerous geological, archaeological, and historical data give incontestable evidence that during the last 4500 to 5000 years the level of the Azov-Black Sea water began to drop with the onset of each of the three cold periods and began to rise with the onset of each of the three warm periods (present period included). The main reason for this phenomenon, apart from eustatics, is that the centrifugal forces of the Earth's diurnal rotation vary as a result of climatic fluctuations.

* According to the terminology of Fedorov and Skiba.

The level of the Caspian, on the other hand, began to rise with the onset of each cold period and began to drop with the onset of each warm period (present one included). The fact that the level fluctuations in the northern and southern Caspian are not coordinated with one another is especially noteworthy.

The variations in the volume of the Caspian, and also the uncoordination of the level variations in its northern and southern parts, can be explained as follows. The level of this sea is determined not only by the ratio between precipitation and evaporation but also by the diurnal-rotation regime of the Earth.*

Let us assume, for example, that the angular velocity of the Earth is constant in magnitude. In this case the level of the sea will clearly depend mainly on the evaporation rate and on the amount of precipitation falling into its basin. Thus the fluctuations in water level will be the same in all parts of the sea, that is, they will be of the same magnitude and will take place at the same time.

Now let us assume that the amounts of evaporation and rainfall in the sea basin are constant and that the rotational regime of the Earth varies. In such a case we have two possibilities. First, if the diurnal-rotation velocity starts to increase, all the water (both surface and subsurface) in the Aral-Caspian depression tends to shift toward the equator under the influence of the centrifugal forces. In conformity with the geomorphological features of the locality, this water moves toward the southeastern part of the depression (the Caspian basin); in particular, the flows of such rivers as the Amu Dar'ya and Syr Dar'ya will deviate in this direction. As a result, the sea level will rise in this area, since the influx of water from the south remains practically the same while the influx from the north (and especially from the northeast) increases sharply. Consequently, the level of the Caspian rises and the level of the Aral drops correspondingly, just as a result of the redistribution of the water masses of the Aral-Caspian basin caused by an increase in the rotational velocity of the Earth. It is significant that the water level in the southern part of the sea will rise somewhat higher than the level in the northern part.

Next let us assume that the diurnal-rotation velocity decreases. The flow of surface and subsurface water into the Aral-Caspian basin will then tend to shift poleward, and due to the geomorphological features of the locality this flow will become deviated toward the Aral basin. The level of the Caspian will drop, more in the southern part than in the northern part, and the level of the Aral will rise. Actually, as Berg has pointed out, such a behavior of the seas is observed: the fluctuations in the level of the Caspian Sea over the centuries are in general opposite to the fluctuations in the level of the Aral.

Thus the total volume of water in the Caspian depends not only on the precipitation and evaporation there and on possible tectonic movements, but also on the magnitude of the centrifugal forces associated with the Earth's rotation. All these factors are in turn related somehow or other to the fluctuations in climate.

* Essentially, these changes in the level of the Caspian cannot be explained satisfactorily in terms of tectonic causes, since the magnitudes of the level fluctuations and the scales of the tectonic movements are incommensurable.

The Kura. The alluvial plain of the Kura was created mainly during the upper Quaternary. Several large, independent deltas were formed, the river moving on and successively leaving each one behind. In addition to the present delta, five delta formations of the Kura exist. These formations are located alternately to the left and to the right of the river (Egorov, 1959).

This regularity in the evolution of the Kura deltas can be explained in the following way. The deltas located on the right bank of the river (the first, third, and fifth) were formed during periods of climatic cooling. At such times the diurnal velocity of the Earth was higher and the Kura deviated southward under the influence of the centrifugal forces, thus flowing to the south of its previous delta (Figure 9). The deltas on the left bank, on the other hand (the second, fourth, and sixth), were formed during periods of climatic warming, when the Earth's rotational velocity was reduced. At such times the centrifugal forces were less and the Kura deviated northward, thus flowing to the north of its previous delta.

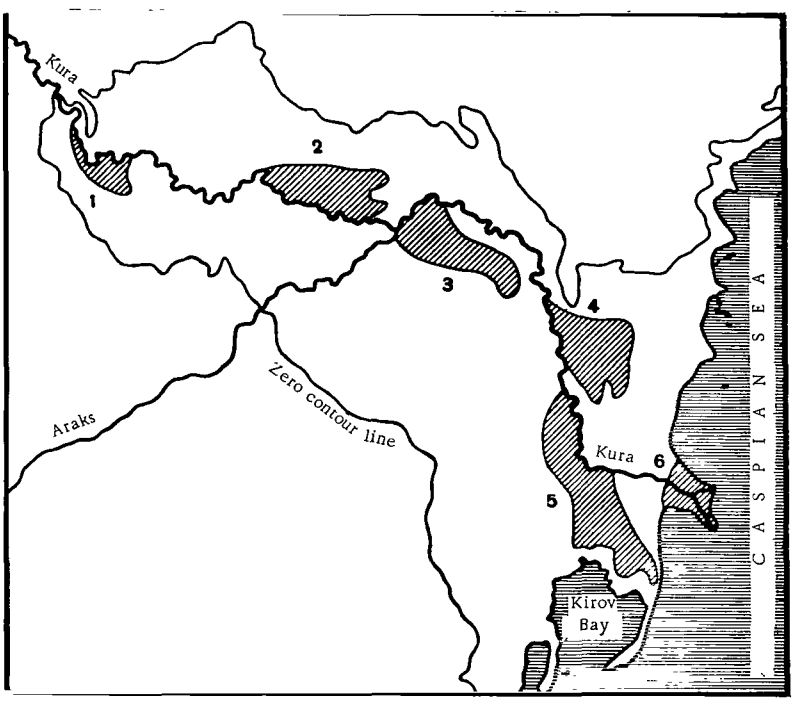


FIGURE 9. Migrations of the Kura.

Consequently, the regular distribution of the deltas of the Kura indicates the fluctuational character of the Earth's diurnal-rotation regime.. Unfortunately, however, due to the lack of data, it is impossible to relate the formation of any of the deltas except the last two to a specific climatic period. We only know that the sixth (last) delta began forming

with the onset of the third (present) warm period, and that the fifth delta (the Sal'yany delta) formed during the third cold period (late Middle Ages). Egorov (1951) notes that the fifth lobate delta of the Kura is about 150 years old. Previously the river discharged into Kirov Bay, and the traces of a vast delta are visible on the banks of the latter.

The Rioni. In general this river follows a westerly course. The Rioni used to divide its flow between two southwestward-flowing estuarine channels, one to the north and one to the south, and empty into the Black Sea near the town of Poti.

Then, with the onset of the third (present) warm period, the Rioni began to deviate to the right; as a result, the flow in the southern branch of the river diminished while the flow in the northern branch increased. In an attempt to check the northward shift of the river, a dam was erected along the right bank of the Rioni, from the Tsivido River to Poti. At the mouth itself, however, where the water rise was especially high, the Poti levee was constructed, to protect the town from floods.

In order to prevent overflowing of the river within the town limits, it was decided to divert some of the water to an artificial channel situated to the north of the actual channels. However, even before the completion of the new channel (the Rionsbros), the river broke through the wall and streamed to the sea. At present up to 90% of the river flows out along the Rionsbros, whereas the mouth of the southern branch has been completely closed off. "The Rioni now occupies a more or less stable position, although there is some tendency toward a further shift to the north" (Motsereliya, 1954).

The Kuban'. In its lower reaches the Kuban' follows in general a westerly course and divides into two main branches: the Kuban' proper, to the south, about 120 km long, and the Protoka, to the north, about 130 km long (Figure 10). Simonov (1958) points out that in its lower reaches the southern branch has repeatedly changed from a southwesterly to a northerly course, thereby emptying into the Black Sea at times and into the Sea of Azov at other times. During the second cold period (antiquity) the river deviated to the left (equatorward) and emptied into the Black Sea. Therefore during the period of Greek colonization the Taman' Peninsula was "many-islanded", comprising the islands of Cimmeria, Phanagoria, Sintica, and others.

With the onset of the warm period in the early Middle Ages, the Kuban' began to shift to the right (poleward). Accordingly, the "many islands" of the Taman' region disappeared and it became a peninsula. At this time the right branch of the river, the Protoka, developed considerably, and most of the discharge was into the Sea of Azov. During the third cold period (late Middle Ages) the river once again deviated to the left (equatorward), and then the main flow was through the Kiziltash and Bugas Lagoons to the Black Sea. Downstream from the Griven Protoka station the river changed course at this time, flowing to the west instead of north-meridionally (a general equatorward shift). During the present warm period the Kuban' is shifting to the north. The studies of Kapitonov and Bramber (1958) verify that at the beginning of the last century the Kuban' emptied into the Black Sea. The influx of water to the Sea of Azov especially increased during the 1850's, however, and the old Kuban' channel leading to the Black Sea gradually became shallow.

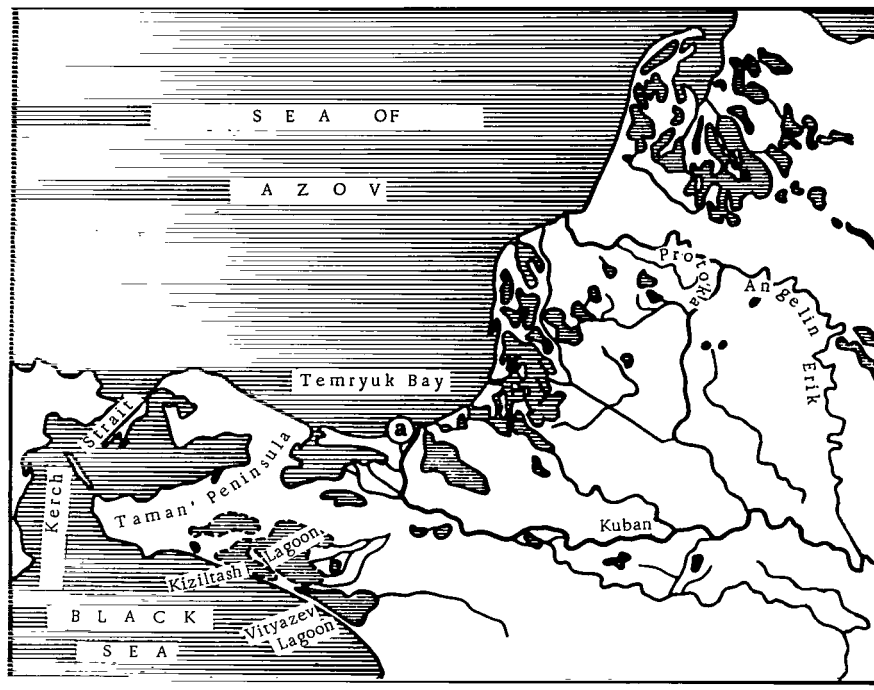


FIGURE 10. Migrations of the Kuban'.

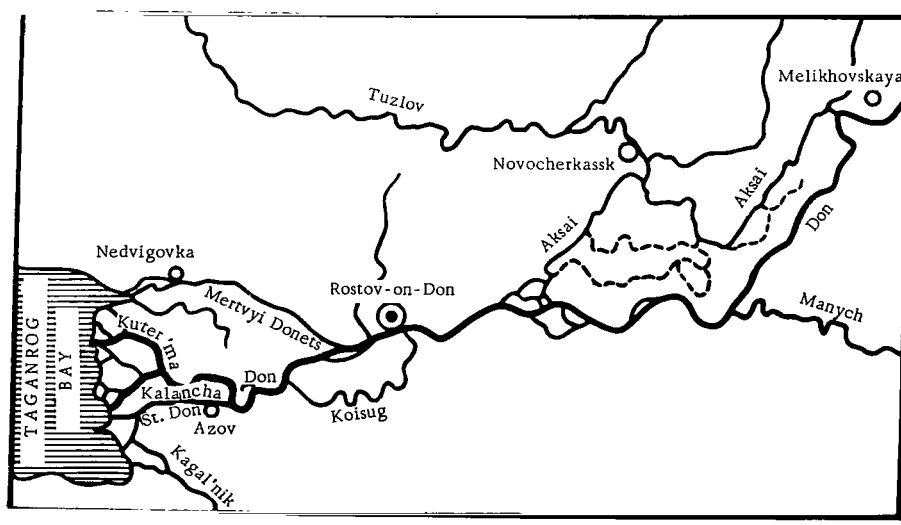


FIGURE 11. Migrations of the Don.

The Don. In its lower reaches this river has a westerly course (Figure 11). Below Melikhovskaya stanitsa* the Don floodplain becomes much broader, forming a delta with a total width of up to 20 km, and the river divides into several branches and distributaries there. The largest of these are the Aksai, the Mertvyi Donets, the Kuter'ma, and the Kalancha. During the second cold period (antiquity), the Don tended to deviate to the left (equatorward). Consequently, the main flow was then along the southern branch, the Staryi Don [the Old Don]. It was on the bank of this well-watered distributary, not far from Elisavetskaya stanitsa, that the large Greco-Scythian trading city of Tanais prospered.

During the second warm period (early Middle Ages) the river deviated to the right (poleward), and most of the flow was along the northern branch (the Mertvyi Donets). A large port town, also named Tanais, is now being built on the bank of this branch, which is beginning to be well supplied with water once again. The new Tanais is not far from the present village of Nedvigovka. The old Tanais, which was located on the left bank, on the Staryi Don, has long since become a ruin.

"... the data for Nedvigovka begin just at the time when the data for the Elisavet settlement terminate... The reason for the move from the Elisavet settlement is quite clear: the previously navigable channel of the river on which the settlement was located, and on which the entire life of this predominantly commercial town must have depended, became silted up... Beginning from the moment when traffic on the river (along which goods were transported) began to be hampered, it must have occurred to the inhabitants to move the main trading point to some place where conditions were more favorable; the region of the present village of Nedvigovka must have been at that time just such a more suitable place" (Knipovich, 1934, p. 195).

During the third cold period (late Middle Ages) the Don deviated to the left (equatorward). As noted by Samokhin (1958, p. 48), at the end of the twelfth century the Venetians founded their colony of Tana not on the Mertvyi Donets, which had already grown shallow by this time, but on the bank of the Staryi Don, which was better supplied with water. After being destroyed by Tamerlane, Tana was rebuilt on its previous site. Then, at the end of the fifteenth century, it was captured by the Turks, who gave it the name of Adzek or Assek (now Azov). Samokhin thinks that the town was shifted to a new site on account of a change in the states of the river channels.

During the third (present) warm period the river has tended to shift to the right (northward). The distributary on which Tana stood accordingly has become shallow, and at present the main flow is more to the north, via the middle branches of Kalancha and Kuter'ma. As a result, the central part of the Don delta is now advancing considerably. Belyavskii (1888) notes that all the southern branches of the river, including the Don (Staryi Don) branch, which was formerly the main branch, have become quite shallow.

The Dniester. In its lower reaches this river flows southeast and empties into the Dniester Estuary. The channel meanders over a broad floodplain, forming a great number of lakes. Through this line of lakes flows the deep Turunchuk River.

* [A stanitsa is a large Cossack village.]

During the third cold period (late Middle Ages) the Dniester deviated to the right (southward), and as a result the supply of water to its left bank became insignificant. With the onset of the present warm period the river began to deviate to the left (northward), and the water supply to the left bank increased. In addition, bifurcation of the river took place: a left branch of the Dniester, the Turunchuk, was formed near the village of Chuburcha. The Turunchuk flows back into the Dniester again at Beloe Lake, which is 60 km from the bifurcation point along the Turunchuk and 130 km from it along the Dniester. Gradually the stream velocity of the Turunchuk began to increase, and its channel developed at the expense of the Dniester; sediment began to be deposited in the Dniester just downstream from the bifurcation point. At present the Turunchuk carries more than 70% of the discharge of the Dniester, which is beginning to show signs of senility. If the Turunchuk continues to develop in this way, then in time the "main" channel of the Dniester will become completely senile, as was the case with the Staryi Dniester [the Old Dniester] during the seventies of the last century. As noted by Kortatstsi (1923) the progressive reduction of the rate of flow of the Dniester and the deposition of sediment in it are resulting in a continually increased development of the Turunchuk at the expense of the Dniester.

The changes undergone by the southward-flowing rivers of the Russian plain must be discussed separately. Both history and tradition provide definite evidence that the Dniester, the Dnieper, the Don, and the Volga, together with their numerous tributaries (and also the Ural and the Emba), had considerably more water in them during the cold period of the late Middle Ages than they do during the present warm period. Accordingly, navigation conditions were previously much better and there were more fish in the rivers.

The Dnieper and its tributaries are becoming shallower (Mossanovskii, 1886). The water level in the Kal'mius has gone down, and navigation has ceased on this river. Another river, the Lugan', has also become shallow. During the course of the last century the Sambek, which flowed into the Sea of Azov and which was formerly abounding in water, dried up; the vessels of Peter I once dropped anchor in the estuary of this river. Two hundred years ago large warships were able to go down the Don from Voronezh to the Sea of Azov, whereas now this river is navigable only in its lower reaches (Davidov and Tsunts, 1958).

In the not too distant past the Ilovlya was quite full of water and abounded in fish. At present, however, after the spring floods abate, there is not even a continual flow of water in this stream. Formerly, it should be noted, a waterway joining the Volga and the Don led along the Ilovlya. The Medveditsa and the Khoper are also now becoming shallow (Kireev, 1961).

The Volga is at present going through a stage of aging; its channel and the lowlands around its mouth are filling up with sediment (Kel'vin, 1933). The Emba has stopped discharging into the Caspian, and the lower reaches of the Ural have had to be joined to the sea by means of special canals (Fedorovich, 1958).

What is the reason for this deterioration of the hydrological conditions in the southern Russian plain during the present period? Clearly, the conditions became worse because climatic changes entailed a corresponding rearrangement of the global drainage system, changing its orientation to

polar. The water-divide line shifted equatorward, the flow gradients of the rivers became less (in accordance with the reduction of the centrifugal forces), and thus the total southward flow became curtailed.

The rivers in question seemed to be "pushed up," and it appeared as if their erosion levels were raised. Thus all of the phenomena typical of rivers in a stage of senility were observed.

The Danube. The Danube delta is triangular in shape, with its vertex in the west and its base along the Black Sea. A straight line drawn from the vertex to the sea would be about 80 km long (Figure 12), and the edge of the delta along the sea is about 150 km long. In its delta the Danube divides into three main distributaries: the Chilia, in the north; the Sulina, in the middle; and the Sfantu Gheorghe, in the south.

FIGURE 12. Migrations of the Danube.

During the third cold period (late Middle Ages) the river deviated to the right (equatorward), and the main flow was along the southern and middle distributaries. At that time the southern part of the delta advanced more rapidly than the northern part. With the onset of the present period of climatic warming, the Danube began to deviate to the left (poleward), and consequently the bulk of the flow shifted to the Chilia branch, which at present carries about 70% of the total discharge (Zenkovich, 1958).

The rate of advance of the northern part of the delta has increased accordingly. Over the last hundred years this part has moved more than 6 km out into the sea.

The Neman. In its lower reaches this river has in general a westerly course. The branches of the Neman which supply the most water are: the Atmata, the Skvirite, the Gilge, and the Njemen. During the third cold period (late Middle Ages) the Neman tended to deviate to the left (equatorward), and a considerable part of its discharge was along the southern branch, the Njemen. With the onset of the present period of climatic warming, the river began to deviate to the right (poleward). The part of the delta which is actively expanding at present is thus the region between the mouths of the northern branches, the Skvirite and the Atmata. As Gudelis (1959) notes, the water arteries in the Neman delta are shifting to the north; consequently, some of the southern branches (for example, the Njeman) have lost their connection with the main channel and have embarked upon an independent existence. The general development of the southern part of the delta during the present period is marked by an appreciable amount of stagnation.

The Po. This river has in general an easterly course. Together with the Volano, Adige, and Brenta Rivers, it has formed a large common delta between the Lagoon of Venice in the north and the Lagoon of Comacchio in the south. The existence of five ancient mouths of the Po are evidence of the migrations of this river. We do not have sufficient data to identify chronologically the activity periods of these mouths with any climatic periods. All the same, there is some reason to assume that the river tended to deviate equatorward during cold periods and poleward during warm periods. For example, during the second cold period (antiquity), the mouth of the Po was not far from the Comacchio lagoon, that is, more toward the south than at present. The famous Etruscan port of Spina, which reached its high point in the fourth century B.C., was situated on the southern branch of the Padus (as the Po was then called).

With the onset of the warm period the mouth of the Po moved toward the pole, and the southern branches became silted up. Moreover, whereas in antiquity the site of the city was quite high up above the sea, during the early Middle Ages it gradually sank down below sea level, under the influence of the eustatic factor and as a result of the "water-overflow" effect. The city of Spina lost its importance as a major trading center and gradually went into a decline. By the first centuries A.D. there was only a small village on the site.

Northern part of Mediterranean. The northern Mediterranean is situated in approximately the same latitudes, and in the same general locality relative to the oceans and continents, as the Azov-Black Sea basin. Consequently, the long-term level fluctuations in the part of the Mediterranean north of the Gibraltar parallel are synchronous with those in the Azov-Black Sea basin, the amplitudes of the fluctuations being greater in the direction of the pole.

The course of the level variations in the northern Mediterranean during the last 2500 years is indicated by the behavior of the world's oldest "tide gauge," the temple of Serapis. This temple was built on the shore of the Bay of Naples, near the town of Pozzuoli, at the end of the second period of climatic cooling (second century B.C., or, according to some sources,

somewhat later). At the beginning of the warm period in the early Middle Ages, the temple was found to be several meters below sea level. Then, during the third cold period (late Middle Ages), it came out of the water completely (Figure 13). The low level of the sea at this time is also verified by the fact that in 1501 to 1503 the king of Naples sold (at a low price) some pieces of land which had been freed from the sea; in particular, he presented the area adjoining Pozzuoli to the university of that town.

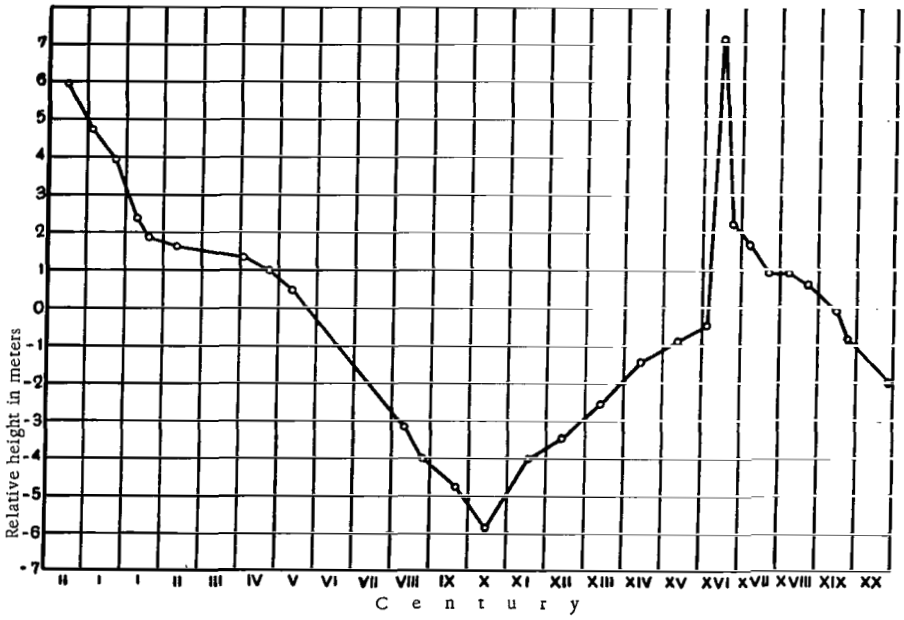


FIGURE 13. Height of Serapis temple relative to sea level.

In accordance with the warmer climate during the present period, the temple of Serapis has once again begun to be submerged, and its floor is already more than 1.5 meters below sea level.

The sea is also advancing in other parts of the northern Mediterranean. For example, during each ten-year period Venice sinks no less than 5 cm into the sea. A place situated on the lower reaches of the Po became submerged under 18.7 cm of water between 1902 and 1950. This raising of the level of the sea should explain the abrasive character of the shores in the northern Mediterranean, and also the fact that there are not a considerable number of beaches there.

The World Ocean. Data from precise grading measurements indicate that during the present period the level of the World Ocean has a slope from the poles to the equator. As Shokal'skii (1959, p. 80) points out, the position of the average multiannual sea level from south to north is rising gradually. This has been noted in North America for both the Atlantic and Pacific, and it has been verified in the Soviet Union. However, Shokal'skii does not cite the reason for the indicated phenomena. Apparently, the

phenomena in question are caused by the secular decrease in the diurnal-rotation velocity of the Earth (and thus in the centrifugal forces), which is in turn a result of the present climatic warming.

III. CONCLUSION

We have considered, unfortunately in a very cursory and fragmentary way, the "behavior" of more than 30 hydrological objects (13 water bodies and 22 rivers) during various intervals of historical time. Our conclusions concerning some of these may be somewhat unjustified, but for an overwhelming majority of the objects these conclusions are backed up by quite adequate factual evidence.

A great number of facts indicate that, at least during the last 4500 years, periodic planet-wide rearrangements of the drainage system have taken place. Accordingly, water bodies and streams have tended to shift toward the equator during cold periods and toward the poles during warm periods. There is only one possible explanation of this correlation between the changes in the drainage system and the fluctuations in climate: the correlation must exist due to corresponding fluctuations in the Earth's angular velocity, caused by climatically induced redistributions of the water mass on the Earth's surface. The redistributions take place in a meridional direction, parallel to the diurnal-rotation axis of the planet.

In general, during the course of geological time the hydrosphere influences the diurnal-rotation regime in two ways. First of all, it transforms gravitational energy into mechanical energy of the diurnal rotation: it slows down, or brakes, this rotation. Second, the hydrosphere becomes shifted poleward or equatorward to some extent or other, as a result of hydroatmospheric processes, thereby changing the moment of inertia of the rotating body (the Earth). Thus, ultimately it transforms solar thermal energy into mechanical energy of diurnal rotation, and it imparts a fluctuational character to this rotation. Consequently, the observational data indicating that the secular variations in the Earth's rotational regime cannot be accounted for solely in terms of a tidal mechanism are quite to be expected.

At present it is difficult to judge to what extent the so-called spasmodic variations in the angular velocity of the Earth, which can become appreciable over the course of some years, are climatically induced. The correlation of these variations with climatic fluctuations during the last two or three centuries (and also their correlation with the level fluctuations of the ocean and the Caspian Sea), however, has been demonstrated convincingly by Maksimov (1954, 1960). It is interesting that the drainage system even responds appreciably to these fluctuations in the Earth's diurnal-rotation regime. For example, when the Earth's rotation speeded up considerably during the 1870's and 1880's (during the five years from 1870 to 1875, the Earth "gained" five seconds), the drainage system "responded" to this with a definite tendency toward an equatorward shift.

In addition to the overall, or background, factor (the variations in the centrifugal forces of diurnal rotation), a great many other factors affect the evolution of the drainage system. These factors influence, in particular,

migrations of rivers (especially in their lower reaches) and level variations in water bodies. In the past the influence of the rotational regime of the Earth on the evolution of the planet was not taken into account. Thus, insufficiently substantiated hypotheses were advanced to explain the hydrological phenomena in specific cases, or (what was more frequent) the roles of certain factors were exaggerated.

For example, some archaeologists and geomorphologists (Tolstov, Kes', and others) think that the repeated variations in the courses of the Amu Dar'ya and Syr Dar'ya are principally due to two factors: the accumulation of alluvial deposits, and human intervention. For historical times certain investigators suggest that the second factor (that is, sociopolitical causes) is the most important one. Tolstov (1960) is inclined to explain the migrations of the rivers by the way in which the deltas are formed, since an extremely rapid accumulation of deposits takes place in the deltas, especially in the immediate vicinity of the channels and in the channels themselves. As a result of this the stream very rapidly reaches the top of the embankment around the channel, and of course it attempts to continue its flow via lower places. According to Tolstov, during historical times, when man used the Amu Dar'ya to irrigate his fields, the channel was no longer able to migrate. Man regulated the flow of the river, in an attempt to utilize it in the required direction. Consequently, each time the Amu Dar'ya briefly broke through and flowed along its old channels during historical times, this was related to a period of sudden slackening of the regulative activity of man, as a result of major sociopolitical catastrophes.

Now let us consider in somewhat more detail what parts these two factors actually play in the evolution of the global drainage system. First let us consider channel processes. During the course of its evolution a river tends to develop a so-called equilibrium profile. The river usually enters into this more or less stable state first in its lower reaches and then gradually in its upper reaches as well. If the influx-discharge conditions (that is, the wetness conditions in the basin of the river in question) do not vary as time goes by, and if there are no tectonic movements, the equilibrium profile will depend entirely on the erosion level of the river.

If the erosion level drops, downcutting of the river bed will gradually take place, beginning in the lower reaches, and the elevation of the channel will drop accordingly. If the erosion level of the river rises, on the other hand, then (also beginning in the lower reaches) the channel will gradually begin to fill up with deposits, and its elevation will rise. Thus, the accumulation of sediments in a channel begins only when the water level rises in the body of standing water, as a result of filling of the latter with solid deposits, the erosion level of the channel being raised accordingly. Only in such a case will the elevation of the channel be raised and conditions will be favorable for shifting of the stream to a new channel, the probability of a shift in one direction being the same as that of a shift in the other.

However, nothing of this sort is observed, for example in the case of the Amu Dar'ya. During periods when its erosion level dropped, regardless of whether it flowed into the Aral Sea, Lake Sarykamysh, or the Caspian, this river (or more precisely its corresponding branches) filled up its channel with deposits rather than deepening it, the accumulation of deposits being the most intensive in the head reaches of the various branches. Thus

it is clear that in this case the accumulation of deposits was in no way related to variations in the erosion level, and that it was determined solely by a decrease in the stream velocity (that is, by a reduction of the total amount of water flowing into the given branch). In other words, the channel processes do not cause a reduction of the water discharge, but rather the opposite is true: a reduction of the discharge produces the corresponding channel processes.

A study of the ancient irrigation, and also certain historical data, indicate that the extensive irrigation constructions in the delta regions of the Amu Dar'ya, the Syr Dar'ya, and other rivers were erected at times when these localities had received an abundant natural supply of water for a long time. In those times the problem was not so much to ensure a sufficient supply of water as to ensure its maximum utilization. However, as time went by, this well-watered phase of the cycle was succeeded by another phase in the utilization of the given region for irrigation farming: a poorly watered phase during which the total influx of water to the canals gradually became less. Then the problem was one of ensuring a sufficient supply of water. In order to solve this problem the inhabitants were compelled to carry out large-scale clearing and deepening of the canals, to move the canal heads upstream, to erect dams, etc.

As pointed out by Tolstov (1947), the inhabitants then apparently hauled up and brought back to their fields the gradually disappearing water of the drying branches of the river. Thus, in spite of the fact that during the second phase man, by means of his intervention, even improved the water-supply conditions in this area, this supply nevertheless diminished, and after a time it was cut off completely, for reasons which had nothing to do with human activity. Man in this case only succeeded in retarding, to some extent, the naturally occurring process.

Makeev (1952, p. 554-562) thinks that the abandonment of lands for socioeconomic reasons cannot create natural conditions which will prevent their subsequent irrigation. When lands suitable for irrigation are abandoned for centuries, this just indicates that it is impossible to supply these lands with water without carrying out large-scale operations. The people who live by working this land will not be easily induced to leave the cultivated area, and they will take all possible measures to continue its irrigation. The previously cultivated lands on the Kunya Dar'ya and the Zhana Dar'ya apparently became neglected because the flow of water along these channels ceased, as a result of natural causes.

We have seen that certain regularities in the development of all rivers, for instance the simultaneity of their changes in course and the fact that these changes are confined to definite climatic periods (equatorward deviation of rivers during warm periods and poleward deviation during cold periods), can be accounted for neither by a slackening of the regulative activity of man nor by any kind of channel processes. Thus it follows that climatically induced fluctuations in the length of the terrestrial day must be the main, or background, cause of periodic river migrations on a world-wide scale.

We have pointed out that the course of the Earth's evolution, with respect to many of its important features, is determined by three regularities. This has been the case ever since a certain stage in the evolution of our planet when water appeared on the Earth's surface and the division of this surface into dry land and sea took place. From this time on, it

became possible for water to change from liquid to solid (snow, firn, or ice), and vice versa. Thus conditions were created which were conducive to periodic redistributions of the water mass relative to the poles and the equator (via hydroatmospheric processes produced by a change in the overall external thermal balance of the Earth). These important regularities in the evolution of the Earth may now be summarized as follows:

1. **First-order regularity in the evolution of the Earth.** Three factors, climate, diurnal-rotation regime, and tectonics, stand in a mutual cause-effect relationship to one another. Any variation in one of these factors, no matter what its cause, will inevitably entail corresponding variations in each of the others.

2. **Second-order regularity in the evolution of the Earth.** This regularity, which is a consequence of the first-order regularity, states that at any given moment of time the differences in the physicomechanical properties of the geospheres (lithosphere, hydrosphere, and atmosphere) give to the figure of the Earth a kind of triple character, as a result of fluctuations in the length of the terrestrial day. The degrees of flattening of these geospheres, in the sense of their conformity to a new rotational regime, will in general not be identical. Exactly identical oblateness of all three geospheres is possible only if the Earth's diurnal-rotation velocity remains constant for quite a long time. With respect to the dynamics of the Earth, this means that any variation in the diurnal velocity inevitably leads to a corresponding "triple pulsation" of its geospheres parallel to the axis of rotation.

3. **Third-order regularity in the evolution of the Earth.** This regularity is a consequence of the second-order regularity. The pulsational shifts of the hydrosphere relative to the lithosphere, parallel to the diurnal-rotation axis of the Earth, result in periodic rearrangements of the entire global drainage system, sometimes toward the poles and sometimes toward the equator. These planet-wide rearrangements form a background for all the other possible changes in the drainage system. The latter may result from, for example, tectonic movements, the filling of standing-water bodies with deposits, a change in the ratio between the arrival and departure of moisture, human activity, etc. It might be said that rivers act more or less like gigantic pendulums, which oscillate with different periods and amplitudes under the influence of the varying centrifugal forces. Lakes and seas, on the other hand, act more or less like carpenter's levels, and they also indicate some particular state of the rotational regime of the Earth. In the long run, both the pendulums (rivers) and the levels (bodies of standing water) serve as indicators of the corresponding climatic fluctuations.

The authors consider it their pleasant duty to express their warmest and most heartfelt thanks to B. A. Apollov, B. L. Lichkov, N. I. Makkaveev, K. K. Markov, and A. V. Shnitnikov for reading through the manuscript of this article and for giving valuable advice and recommendations.

:FERENCES

ARANDARENKO, G. A. Dosugi v Turkestane (1874-1889) (Leisure Time in Turkestan (1874–1889)). 1889.

Arkheologicheskaya karta Kazakhstana (An Archaeological Map of Kazakhstan). — AN SSSR, Institut istorii, arkheologii i etnografii. 1960.

BALANDIN, V. M. Sopostavlenie urovnya r. Volgi v Astrakhani s kolebaniyami urovnya morya v Baku (A Comparison of the Level of the Volga at Astrakhan with Sea-Level Fluctuations at Baku). — Izvestiya Tsentral'nogo Gidrometeorologicheskogo Byuro, No. 8. 1929.

BARTOL'D, V. V. Svedeniya ob Aral'skom more i nizov'yakh Amu-Dar'i s drevneishikh vremen do XVII v. (Information on the Aral Sea and the Lower Reaches of the Amu Dar'ya from Ancient Times up to the XVII Century). — Nauchnye Resul'taty Aral'skoi Ekspeditsii, No. 2. 1902.

BARTOL'D, V. V. K istorii orosheniya Turkestana (The History of Irrigation in Turkestan). 1914.

BELYAVSKII, P. E. Donskie girla. Gidrograficheskoe issledovanie Komissiya dlya ochistki i soderzhaniya v ispravnosti donskikh girl (The Don Distributaries. A Hydrographical Study by the Commission for Cleaning and Maintaining the Distributaries), Odessa. 1872.

BERKALIEV, Z. T. Gidrologicheskie osnovy vodokhozyaistvennogo ispol'zovaniya basseina r. Ili (Hydrological Fundamentals of the Aquicultural Utilization of the Ili Basin). — Alma-Ata, Kazakhskoe gosudarstvennoe izdatel'stvo. 1960.

CHERNOV, A. Nizov'ya Etszin-gola (The Lower Reaches of the Edsin Gol). — Izvestiya Imperatorskogo Russkogo Geograficheskogo Obshchestva, **44**, (7). 1908.

CHOU TIN-JU and CHAO-CHI. Migratsiya Tarima v ego srednem techenii. Kun'-Lun i Tarim. Ocherk prirodnykh uslovii (Migrations of the Tarim in Its Middle Reaches. The Kunlun and the Tarim. An Outline of the Natural Conditions). — Izdatel'stvo AN SSSR. 1961.

DZENS-LITOVSKII, A. I. Geologiya i rel'ef kul'turnogo sloya oazisov Srednei Azii (The Geology and Topography of the Cultivated Soil Layer of Oases in Central Asia). — AN SSSR, Priroda, No. 4. 1934.

DZHUMBAEV, O. M. K istorii oroshaemogo zemledeliya v Turkmenistane (The History of Irrigation Farming in Turkmenistan). — Izdatel'stvo AN Turkmenskoi SSR.

EGOROV, V. V. Obshchie zakonomernosti formirovaniya primorsko-del'tovykh ravnin (General Regularities in the Formation of Maritime-Delta Plains). — Izvestiya AN SSSR, Seriya Geograficheskaya No. 4. 1955.

EIGENSON, M. S. O solnechnom upravlenii vrashchatel'nym dvizheniem Zemli (Solar Control of the Rotational Motion of the Earth). — Informatsionnyi Byulleten', No. 1. 1958.

EIGENSON, M. S. Solnechnaya aktivnost' i geotektonika (Solar Activity and Geotectonics).— In: Geologicheskii sbornik, L'vovskoe geologicheskoe obshchestvo. L'vov. 1958.

FEDOROV, V. P. and A. A. SKIBA. Kolebaniya urovnei Chernogo i Kaspiiskogo morei v golotsene (Fluctuations of the Levels of the Black and Caspian Seas during the Holocene). — Izvestiya AN SSSR, Seriya Geograficheskaya, No. 4. 1960.

FEDOROVICH, B. A. Lik pustyni (The Face of the Desert). — Molodaya gvardiya. 1954.

GUDELIS, V. Geologicheskie i fiziko-geograficheskie usloviya zaliva Kurshyu mares i territorii, okaimlyayushchei zaliv Kurshyu mares. Itogi kompleksnogo issledovaniya (Geological and Physicogeographic Conditions in the Courland Lagoon and in the Territory Bordering on the Courland Lagoon. Results of a Comprehensive Study). — AN Litovskoi SSR. 1959.

GULYAMOV, V. V. Istoriya orosheniya Khorezma s drevneishikh vremen do nashikh dnei (The History of the Irrigation of Khorezm from Ancient Times to the Present). — AN Uzbekskoi SSR. Tashkent. 1957.

ITINA, M. A. Pervobytnaya keramika Khorezma (Primitive Ceramics of Khorezm). In: Sbornik "Keramika Khorezma," edited by S. P. Tolstov and M. G. Vorob'eva, Izdatel'stvo AN SSSR. 1959.

KAPITONOV, E. I. and I. A. BEMBER. Soedinenie r. Kubani s Chernym morem (The Junction of the Kuban' River with the Black Sea). — Priroda. 1958.

KAUL'BARS, A. V. Nizov'ya Syr-Dar'i, opisannye po sobstvennym nablyudeniyam v 1873 g. general'nogo shtaba polkovnikom baronom A. V. Kaul'barsom (The Lower Reaches of the Syr Dar'ya, Described on the Basis of Personal Observations Made in 1873 by Colonel of the General Staff Baron A. V. Kaul'bars. — Edited by R. E. Lents. — Imperatorskaya Akademiya Nauk. Sankt-Peterburg. 1881.

KEL'IN, N. V. Erozionnye i akkumulyativnye protsessy v nizov'yakh i del'te r. Volgi (Erosion and Accumulation Processes in the Lower Reaches and the Volga Delta). — Zemlevedenie, 35, 1. Gosudarstvennoe tekhniko-teoreticheskoe izdatel'stvo. 1933.

KES', A. S. O kolebaniyakh Aral'skogo morya (Fluctuations of the Aral Sea). — Priroda, No. 1. 1958.

KHAIDAROV, R. M. O dinamike ruslovykh protsessov v del'te r. Ili (The Dynamics of Channel Processes in the Ili Delta). — Trudy Gidroproekta, Gosstroiizdat. 1960.

KIREEV, A. F. Umirayushchaya reka (A Dying River). — Priroda, No. 5. 1961.

KNIPOVICH, T. N. K voprosu o torgovykh otnosheniyakh grekov s oblast'yu r. Tanaisa v VII-V v. do n. e. Iz istorii Bospora (The Commercial Relations of the Greeks with the Tanais Region in the Seventh to Fifth Centuries B. C. A Contribution to the History of the Bosporus). — Sotsial'no ekonomicheskoe izdatel'stvo. 1934.

KOLESNIKOV, S. V. Kratkii kurs obshchego zemlevedeniya (A Short Course in Geography). — Geografgiz. 1957.

KORTATSTSI, A. I. Iz itogov meliorativnykh issledovanii 1923 g. NKZ (From the Results of Reclamation Studies Made in 1923 by the NKZ). — Trudy Yuzhnoi oblastnoi meliorativnoi organizatsii. Odessa. 1924.

KOZLOV, P. K. Mongoliya i Amdo i mertvyi gorod Khara-Khoto (Mongolia and Amdo and the Dead City of Khara Khoto). — Geografgiz. 1948.

KROPOTKIN, P. N. Yavleniya szhatiya i rastyazheniya v zemnoi kore i vozmozhnosti ikh izucheniya v kore. Problemy tektonofiziki (Contraction and Expansion Phenomena in the Earth's Crust and the Possibility of Studying Them in the Crust. Problems in Tectonic Physics). — Gosgeoltekhizdat. 1960.

KUFTIN, B. A. Materialy k arkheologii Kolkhidi (Data for an Archaeology of Kolkhida), Vol. 1. 1948; Vol. 2. 1950. — Tekhnika da Sheroma, Tbilisi, kombinat pechati upravlenii po delam poligrafii i izdatel'stv.

KUNIN, V. N. Karakumskie zapiski (Kara Kum Notes). — Geografgiz. 1952.

KUNIN, V. N. O podzemnykh vodakh podgornykh ravnin v predelakh Sin'tszyana (Subsurface Water in the Foothill Plains of Sinkiang. In: Prirodnye usloviya Sin'tszyana, Izdatel'stvo AN SSSR. 1960.

KUZNETSOV, V. G. and E. M. MURZAEV. Ozero Bagrashkul' i ego budushchee (Lake Baghrash Köl and Its Future). — In: Prirodnye usloviya Sin'tszyana, Izdatel'stvo AN SSSR. 1960.

LENTS, R. E. Nashi svedeniya o prezhnem techenii Amu-Dar'i (Our Data on the Previous Flow of the Amu Dar'ya). — Zapiski Imperatorskogo Russkogo Geograficheskogo Obshchestva, Vol. 4, (po obshchei geografii). 1871.

LICHKOV, B. L. O svyazi mezhdu izmeneniyami struktury zemli i izmeneniyami klimata (The Correlation between Changes in the Earth's Structure and Climatic Changes). — Doklady na ezhegodnykh chteniyakh pamyati L. S. Berga, I-III, Izdatel'stvo AN SSSR. 1958.

LICHKOV, B. L. Edinstvo prirodnykh vod i formirovanie podzemnykh vod (The Unity of Natural Water and the Formation of Subsurface Water). — Vsesoyuznyi 3-i gidrologicheskii s"ezd. Vol. 7. 1959.

MAKEEV, P. S. Zemli drevnego orosheniya na sukhikh ruslakh Kunyadar'i i Zhandar'i (Ancient Irrigated Lands along the Dry Channels of the Kunya Dar'ya and Zhana Dar'ya). — Izvestiya Vsesoyuznogo Geograficheskogo Obshchestva, 84(6). 1952.

MACHAČEK, F. The Topography of the Earth. Experience of a Personal Morphological Description of the Earth's Surface [Russian translation. 1959.]

MAKKAVEEV, N. I. Erozionno-akkumulyativnye protsessy i rel'ef rusla reki (Erosion-Accumulation Processes and the Topography of a River Channel), No. 1. — Geografgiz. 1952.

MAKSIMOV, I. V. Vekovye kolebaniya ledovitosti Atlantiki (Secular Fluctuations in the Iciness of the Atlantic). — Trudy Instituta Okeanologii, Vol. 3, Izdatel'stvo AN SSSR. 1954.

MAKSIMOV, I. V. Nekotorye voprosy izucheniya mnogoletnikh kolebanii ledovitosti arkticheskikh morei (Some Problems in the Study of Multiannual Fluctuations in the Iciness of the Arctic Seas). — Problemy Arktiki i Antarktiki, No. 2, Izdatel'stvo Morskoi transport. 1960.

MARTYNOV, D. Ya. Veka i mgnoveniya (Centuries and Moments). — Izdatel'stvo MGU. 1961.

MASSON, V. M. Izuchenie kul'tury drevnego Dakhistana v 1951 g. (A Study of the Culture of Ancient Dakhistan Made in 1951). — Izvestiya AN Turkmenskoi SSR, No. 1, Ashkhabad. 1953.

MASSON, V. M. Missrianskaya ravnina v epokhu pozdnei bronzy i rannego zheleza (The Messerian Plain during the Late Bronze and Early Iron Ages). — Izvestiya AN Turkmenskoi SSR, No. 2. 1954.

MASSON, M. F. O kolebaniyakh klimata Srednei Azii v svyazi s voprosom ob izmeneniyakh rezhima vod za istoricheskii period (Climatic Fluctuations in Central Asia, in Relation to the Question of Variations in the Water Regime during the Historical Period). — Trudy Uzbekskogo Geograficheskogo Obshchestva, Izdatel'stvo AN Uzbekskoi SSR. 1948.

MOISEENKO, V. S. Airan-Kul' — kochuyushchee ozero Dzhungarii (Ayran Köl, the Wandering Lake of Dzhungaria). — Izvestiya AN SSSR, Seriya Geograficheskaya, No. 5. 1959.

MOTSERELIYA, A. V. Preobrazovanie Kolkhidy (The Transformation of Kolkhida). — AN SSSR. 1954.

MURZAEV, E. M. Geograficheskie nablyudeniya v Dzhungarii (Geographical Observations in Dzhungaria). — Izvestiya AN SSSR, Seriya Geograficheskaya, No. 2. 1959.

MURZAEV, E. M. — Geologiya SSSR, Vol. XXII. Turkmenskaya SSR, Chap. 1, geologicheskoe opisanie. Edited by N. P. Luppov. 1957.

MURZAEV, E. M. Neprotorennymi putyami. Zapiski geografa (Untrodden Paths. Notes of a Geographer). — Molodaya gvardiya. 1954.

MURZAEV, E. M. Fiziko-geograficheskaya kharakteristika severnoi chasti Tarimskoi vpadiny i ee raiony (A Physicogeographic Characterization of the Northern Part of the Tarim Basin and the Surrounding Region). — Izvestiya AN SSSR, Seriya Geograficheskaya, No. 5, 1959.

NESTERUK, F. Ya. Vodnoe khozyaistvo Kitaya (The Water Economy of China). — In: Istoriya nauki i tekhniki Kitaya, Collection of Articles, Izdatel'stvo AN SSSR. 1955.

PARASCANDOLA, A. Y. Fenomeni brodisismici del Serapeo di Pozzuoli. Napoli. 1947.

PARIISKII, N. N. Neravnomernost' vrashcheniya Zemli (The Irregularity of the Earth's Rotation). — Izdatel'stvo AN SSSR. 1954.

POPOLZIN, A. G. Ozera tsentral'nogo Kazakhstana (Lakes of Central Kazakhstan). — In: Problemy vodosnabzheniya tsentral'nogo Kazakhstana, Sbornik statei, Izdatel'stvo AN KazSSR. 1960.

POPOV, I. V. Zhizn' rechnogo rusla (The Life of a River Channel).— Gidrometeoizdat. 1955.
PRZHEVAL'SKII, N. M. Ot Kul'dzhi za Tyan'-Shan' i na Lobnor (From Kuldja Beyond the Tien Shan to Lop Nor). Introductory Article by E. V. Murzaev.— Geografgiz. 1947.
RECLUS, É. Zemlya i Lyudi (The Earth and People).— Vseobshchaya Geografiya, No. 4, Vol. 6. 1896.
RODIONOV, M. F. Materialy po izucheniyu kolebanii Severnogo Kaspiya (Data from a Study of Fluctuations of the Northern Caspian).— Izvestiya Tsentral'nogo Gidrometeorologicheskogo Byuro, No. 8. 1929.
ROGOV, M. M. Gidrologiya del'ty Amu-Dar'i (The Hydrology of the Amu-Dar'ya Delta).— Gidrometeoizdat. 1957.
ROMODANOVA, A. P. Geomorfologiya i chetvertichnye otlozheniya mezhdurech'ya Yu. Bug - Dnestr v predelakh Prichernomorskoi vpadiny (Geomorphology and Quaternary Deposits in the Interfluvial Area between the Southern Bug-Dniester, within the Limits of the Black Sea Depression).— Kiev, Izdatel'stvo AN SSSR. 1951.
SAMOILOV, I. V. Ust'ya rek (The Mouths of Rivers).— Geografgiz. 1952.
SAMOKHIN, A. F. Reka Don i ee pritoki (The Don River and Its Tributaries).— Izdatel'stvo Rostovskogo universiteta. 1958.
SHARPLEY, K. The Change of the Climate [Russian translation. 1958].
SHISHKIN, V. A. Arkheologicheskie raboty 1937 g. v Zapadnoi chasti Bukharskogo oazisa (Archaeological Work during 1937 in the Western Part of the Bukhara Oasis).— Uzbekistanskii Filial AN SSSR. 1940.
SHISHKIN, V. A. Nekotorye itogi arkheologicheskikh rabot na gorodishche Varakhsha (1947-1953) (Some Results of the Archaeological Work at the Varakhsha Site (1947-1953)).— Trudy Instituta Istorii i Arkheologii, No. 8, Izdatel'stvo AN Uzbekskoi SSR. 1958.
SHNITNIKOV, A. V. Izmenchivost' gornogo oledeneniya Evrazii v pozdne-i poslelednikovuyu epokhu i ee absolyutnaya khronologiya (The Variability of Mountain Glaciation in Eurasia in the Late- and Post-Glacial Periods and Its Absolute Chronology).— DAN SSSR, 90(4). 1953.
SHNITNIKOV, A. V. Izmenchivost' obshchei uvlazhnennosti materikov severnogo polushariya (The Variability of the Overall Wetness of the Continents in the Northern Hemisphere).— Izdatel'stvo AN SSSR. 1957.
SHNITNIKOV, A. V. Proshloe i budushchee Arala s pozitsii bol'shikh ritmov klimata (The Past and Future of the Aral, with Respect to the Great Rhythmic Cycles of Climate).— Trudy 3-go Vsesoyuznogo gidrologicheskogo s"ezda, Vol. 7, Gidrometeoizdat. 1959.
SHOKAL'SKII, Yu. M. Okeanologiya (Oceanology).— Gidrometeoizdat. 1959.
SIMONOV, A. I. Gidrologiya ust'evoi oblasti Kubani (Hydrology of the Mouth Region of the Kuban').— Glavnoe upravlenie gidrometeorologicheskoi sluzhby pri Sovete Ministrov SSSR, Gosudarstvennyi okeanograficheskii institut. 1957.

SINITSYN, V. M. Tsentral'naya Aziya (Central Asia). — Geografgiz. 1959.
STOVAS, V. M. Peremennost' vrashcheniya Zemli i geotektonika (The Variability of the Earth's Rotation and Geotectonics). — Geologicheskii sbornik. L'vovskoe geologicheskoe obshchestvo, Nos. 5-6. 1958.
TERLETSKII, B. K. Osnovnye cherty gidrologii Kazakhstana (The Basic Features of the Hydrology of Kazakhstan). — Trudy konferentsii po izucheniyu proizvoditel'nykh sil Kazakhstana. Izdatel'stvo AN SSSR. 1932.
TOLSTOV, S. P., A. S. KES', and T. A. ZHDANKO. Istoriya Sarykamyshskogo ozera v srednie veka (The History of Lake Sarykamysh in the Middle Ages). — Izvestiya AN SSSR, Seriya Geograficheskaya, No. 1. 1954.
TOLSTOV, S. P. and A. S. KES'. Istoriya pervobytnykh poselenii na prostorakh drevnikh del't Amu-Dar'i i Syr-Dar'i (A History of Primitive Settlements on the Ancient Deltas of the Amu Dar'ya and Syr Dar'ya). — Voprosy geografii, Sbornik statei, Geografgiz. 1956.
TOLSTOV, S. P. Priaral'skie skify i Khorezm (The Scythians of the Aral Region and Khorezm). — XXV Mezhdunarodnyi kongress vostokovedov, doklady delegatov SSSR, No. 40. Izdatel'stvo Vostochnoi literatury. 1960.
TOLSTOV, S. P. Nizov'ya Amu-Dar'i, Sarykamysh, Uzboi. Istoriya formirovaniya i zaseleniya (The Lower Reaches of the Amu Dar'ya, Lake Sarykamysh, and the Uzboi. History of the Formation and Population). — Izdatel'stvo AN SSSR. 1960.
TROMBACHEV, S. P. K voprosu o vodosnabzhenii yuzhnogo Khorezma (The Problem of the Water Supply in Southern Khorezm). — Vestnik Irrigatsii, No. 7. Tashkent, Izdatel'stvo Turkvodkhoza. 1924.
TSEKHANSKII, I. B. Kharakteristika klimata raionov proektiruemogo Severo-Kaspiiskogo vodokhranilishcha (The Climate in the Vicinity of the Projected North-Caspian Reservoir). — Trudy Okeanograficheskoi Komissi AN SSSR, Vol. 5. 1959.
Turkmenskii kanal (The Turkmen Canal). — Izdatel'stvo AN SSSR. 1951.
UZIN, S. V. Zagadki materikov i okeanov (The Enigmas of the Continents and Oceans). — Detgiz. 1958.
VOZNESENSKII, A. V. O noveishikh dannykh po izucheniyu urovnya Kaspiiskogo morya (The Most Recent Data from the Study of the Level of the Caspian Sea). — Izvestiya Gidrometeorologicheskogo Byuro, No. 6. 1926.
YANSHIN, A. L. Geologiya severnogo Priaral'ya. Stratigrafiya i istoriya razvitiya (The Geology of the Northern Aral Region. Stratigraphy and Evolutionary History). — Moskovskoe Obshchestvo Ispytatelei Prirody. 1953.
ZAICHIKOV, V. T. (editor). Vostochnyi Kitai. Primorskie provintsii (Eastern China. The Maritime Provinces). — Geografgiz. 1955.
Zarubezhnaya Aziya Fizicheskaya geografiya (Non-Soviet Asia. Physical Geography). Edited by B. M. Dobrynin and E. M. Murzaev. — Uchpedgiz. 1956.
ZENKOVICH, V. P. Berega Chernogo i Azovskogo morei (The Shores of the Black Sea and the Sea of Azov). — Geografgiz. 1958.

P.S. Veitsman

DEEP SEISMIC SOUNDING AND STUDIES OF THE STRUCTURE OF THE EARTH'S CRUST IN THE USSR

A symposium on deep seismic sounding of the Earth's crust took place on 14—19 November 1960, at the Institute of Earth Physics of the Academy of Sciences of the USSR. The symposium was organized by this institute, the Council of Prospecting Geophysics of the Presidium of the Academy of Sciences of the USSR, the Geophysics Department and the All-Union Institute of Geophysical Prospecting of the Ministry of Geology and the Conservation of Natural Resources of the USSR.

Geologists and geophysicists have become increasingly interested in the internal structure of the Earth, and especially in its peripheral part, i.e., the Earth's crust and the outer mantle. This subject is also of interest to astrophysicists; although the Earth is the most accessible planet of the solar system, very little is known as yet concerning its internal structure.

Increasingly detailed and thorough studies of the crust and the mantle are required for the solution of several basic problems confronting modern science, such as the developmental trend of the Earth's crust in different geological periods, the origin and evolution of the continents and oceans, the distribution patterns of mineral resources, and many other subjects of purely scientific as well as practical importance.

The structure of the Earth's crust is investigated by means of several geological and geophysical methods, the seismic method being the principal one. Deep seismic sounding (DSS) is the most detailed of the available seismic methods for studying the Earth's crust; it is based on the study of seismic waves generated by special small-scale explosions. Application of DSS to the study of the structure of the crust on land was developed by Soviet scientists according to principles suggested by G.A. Gamburtsev, and with his direct participation. He was the first to study the internal structure of the crust by means of principles and techniques which had originated in seismic prospecting. Prior to his work these had been employed only in seismology for investigating seismic waves generated by earthquakes, and had provided very scant information. At present DSS is being used extensively in the USSR, both for pure scientific research and for practical industrial purposes.

Outside the USSR similar studies on land are being performed on a considerably smaller scale. However, a method similar to DSS for oceans was developed for the first time by American and British scientists, and is widely used in investigating the Earth's crust within the boundaries of the World Ocean. In the USSR seismic prospecting on the seas and oceans was begun in 1956. Working methods were considerably improved by Soviet scientists who took into account experience acquired in DSS work on land as well as experience in oceanic work accumulated outside the USSR.

In recent years the Soviet Union has amassed extensive data on the application of DSS on land, in regions with different geological histories, as well as on inland and open seas, and in the transition zone from the Asian continent to the Pacific Ocean.

The symposium on deep seismic sounding organized by the Academy of Sciences of the USSR in November 1960 was necessary for discussions of the results obtained as well as of several methodical and technical difficulties which had arisen. The symposium also purported to develop and improve various aspects of the working methods, to interpret results, and finally to coordinate further work, which is being undertaken by an increasing number of organizations.

There were 190 participants representing 48 organizations, 21 of which had worked with DSS. Thirty-six papers were read and discussed.

The potentialities of DSS from a geological standpoint were considered by Associate Member of the Academy of Sciences of the USSR V.V. Belousov.

The agenda of the symposium can be divided into three principal categories: 1) working methods and methods for interpreting data obtained by DSS; 2) characteristics of deep seismic waves, and their physical nature and interpretation; 3) further development and improvement of the DSS apparatus and operating methods.

1. Observation methods were considered in a paper, delivered by E.I. Gal'perin, which was written by a group of authors from the Institute of Earth Physics of the Academy of Sciences of the USSR and the Research Institute of Geophysics. The paper compared DSS with other methods for studying the structure of the Earth's crust, and noted the extensive, though not yet fully exploited, possibilities of this method, which is the most detailed. The possibility of using DSS for detecting and interpreting waves reflected from deep interfaces and for utilizing different types of waves (refracted, exchanged, etc.) was emphasized.

The use of reflected waves in DSS was discussed by E. D. Tagai and N.P. Ivanova, as well as by V.Z. Ryaboi and G.G. Shteinberg.

2. Papers of the second category dealt with the results obtained by DSS in regions having different geological histories, including ancient and young shields (such as those of Karelia, the Volga-Ural regions, Turkmenia, and Kazakhstan), intermontane troughs (Fergana, Western Turkmenia, the Kura lowland), folded regions (Tien Shan and Pamir) inland seas (Black and Caspian), and the transition zone from the Asian continent to the Pacific Ocean (the northern coast, the Sea of Okhotsk, the Kurile Island Arc and its accompanying trench, and the northwestern margin of the Pacific). Papers on these subjects were presented by I.V. Litvinenko. I.V. Pomerantseva, A.V. Egorkin, K.E. Fomenko, A.A. Popov, B.S. and I.S. Vol'vovskii, B.D. Trebukova, T.L. Vasil'eva, Yu.M. Neprochnov, P.S. Veitsman, E.I. Gal'perin, N.I. Davydova, I.P. Kosminskaya, R.M. Krakshina, and others.

The majority of the authors devoted most of their attention to the characteristics of wave patterns and the determination of the physical nature of the recorded waves.

B.S. and I.S. Vol'vovskii, I.V. Pomerantseva, I.V. Margot'eva, and A.V. Egorkin reported that alongside the head waves the records often show deep waves similar to refracted ones, as well as waves reflected from Moho beyond the limiting angle.

A. S. Alekseev presented some theoretical results, while A. M. Epinat'eva and A. G. Aver'yanov presented analyses of experimental data and calculations for certain specific models of a medium approximating different Earth crust models in its basic features.

I. P. Kosminskaya reported on work done by several authors in the transition zone from the Asian continent to the Pacific, as well as on an analysis of the various wave patterns obtained in different areas of the investigated region. Observations on seas and oceans permit a much more comprehensive use of the dynamic and kinematic properties of the recorded waves. The advantage derives mainly from the constant conditions for the generation and recording of vibrations as well as from similarities in the directional characteristics of the source and the detector. Analysis of the kinematic and dynamic features of the recorded wave patterns revealed, and made possible the utilization of the head waves related to deep interfaces as well as of refracted and reflected waves and those of more complex types, such as multiple and exchange waves.

Preliminary results obtained by using the entire variety of wave patterns make it possible to determine the most probable velocity sections of the Earth's crust which are characteristic of the different areas investigated, thereby isolating several corresponding types of crustal structure, the most distinct being the continental type (characteristic of shields), the oceanic, and the transitional.

Yu. N. Godin presented his concept of the multilayer structure of the Earth's crust, involving the absence of the so-called classical layers (the granite and the basalt layers), and assuming the presence in the crust of only metamorphic sedimentary complexes of various geological ages. His viewpoint was supported by I. A. Rezanov. Godin also suggested that in the near future work should be restricted to methodical experiments aiming at refining DSS. He stated that in its present form this method cannot solve practical problems concerning the distribution patterns of mineral resources, and therefore the time has not yet come for its large-scale implementation for regional investigations.

A different viewpoint was developed by V. V. Fedynskii, B. A. Petrushevskii, I. P. Kosminskaya, and others who claimed that along with the search for further improvements, more extensive use be made of DSS, which has been adopted in practice as part of the efficient complex of regional geophysical investigation methods.

Petrushevskii insisted on extensive use of DSS even for determining the more general structural features of the Earth's crust for purposes of regional geotectonic zoning, which directly provides an efficient basis for the prospecting of minerals. According to this author DSS provides the most powerful tool for investigating the deep layers of the Earth's crust that has yet been invented; the failure to implement this method cannot be justified.

The symposium discussed the characteristics of waves, the nature of seismic boundaries, and the structural variety of the Earth's crust, as well as results obtained by comparing seismic and gravimetric data.

Several papers were devoted to studies of wave patterns recorded during earthquakes and powerful explosions. Papers on this subject were delivered by S. I. Masarskii, N. I. Bulin, E. M. Butovskaya, and D. D. Sultanov.

3. Some of the papers dwelt on the shortcomings of the existing apparatus and ways to eliminate them. Their authors complained about the limited application of the most modern achievements of radioelectronics, etc. The principal speakers on this subject were A.N. Mozzhenko and S.I. Ivanov.

Yu.P. Neprochnov spoke on the use of radio buoys in maritime work; V.S. Voyutskii reported on the use of accumulation methods for improving the effective sensitivity in working on land. Observation methods and techniques were discussed by M.A. Zaionchkovskii.

Several papers were concerned with further development of DSS and seismic prospecting in general, including the nature of waves, the nature of seismic boundaries, the intensity of waves and their frequency spectrum as functions of the weight of charge, low-frequency seismics, the use of spectroscopy, etc. These contributions were made by A.M. Epinat'eva, G.N. Pariiskaya, G.G. Mikhota, Yu.I. Vasil'ev, L.L. Khudzhinskii, and others.

The symposium adopted a resolution which enumerated several disadvantages of DSS, and also suggested ways to eliminate them, and to further improve and develop this method, as well as conditions for its most efficient use in conjunction with other geophysical methods.

The following is a brief summary of the principal recommendations by the symposium:

1. Continuation and expansion of work on DSS for investigating the inner structure of the crust, primarily in regions of a basically different geological structure.

2. Organizing the planning and coordination of DSS work in conjunction with other geophysical methods for investigating the structure of the Earth's crust, initially with the aid of gravimetric and aeromagnetic methods. For this purpose an interdepartmental coordination commission for deep geophysical investigations will be established.

3. Special experimental research methods for improving DSS on sea and on land.

4. Continuation and expansion of research on dynamic wave characteristics, devising methods for the interpretation of refracted and deep reflected waves.

5. Designing of new apparatus based on the most modern achievements of radioelectronics and instrumentation.

6. Generalization of all DSS data obtained in the USSR over the last 10 years. Not only is this in itself of scientific interest, but it is also necessary for devising a reliable and uniform interpretation method and an efficient complex of geophysical methods for investigating the Earth's crust and the outer portion of the mantle.

7. Expansion of investigations into the physicomechanical properties of rocks under thermodynamic conditions corresponding to those prevailing in the Earth's crust.

8. Improvement of methods for studying the outer portion of the Earth's mantle. Recommendations to Soviet seismologists for more active work on the seismological methods used in studies of the Earth's crust and the and the outer mantle. Utilization of large-scale industrial explosions, performing the observations with DSS and seismological apparatus.

A plan is being devised in the USSR for extensive work on infra-deep drilling for the direct study of rocks in the Earth's crust and the outer mantle under significantly different structural conditions. Deep boreholes are planned as follows: 1) through sedimentary layers into granite; 2) through sedimentary layers into basalt; 3) through granite into basalt; 4) through basalt into Moho, i.e., into the mantle rocks.

It is hoped that the implementation of this plan, besides developing borehole observation techniques, will yield highly valuable information on the composition and nature of the crustal strata and the outer mantle. It will also make possible the most comprehensive use of the inherent possibilities of DSS and the entire complex of geophysical and geological methods for the investigation of the Earth's crust and the outer mantle, leading to a better substantial interpretation of the data. In this manner conditions will be created for a detailed and systematic study of the structure of the Earth's crust on the territory of the USSR, where a great variety of structure and composition can be expected. It will then be possible to solve some of the most important problems of modern Earth science.*

* For the relevant literature the reader is referred to the bibliographical index "Structure of the Earth's Crust and the Outer Mantle According to Geophysical Data" (Stroenie kory i verkhnei chasti mantii Zemli po geofizicheskim dannym), published by the Academy of Sciences of the USSR, Moscow. 1962.

V.A. Tsaregradskii

REGULAR LONG-PERIOD VARIATIONS IN THE VELOCITY OF THE EARTH'S ROTATION AND RELATED DEFORMATIONS OF THE EARTH'S CRUST

A majority of hypotheses on the origin of deformations in the outer portion of the Earth's shell, known as the exosphere or the Earth's crust, attribute deformations exclusively to the intrinsic physicochemical changes of the matter composing the Earth. As a rule, all the assumed alterations of the matter (heating and cooling, phase transitions, recrystallization, differentiation, etc.) ultimately lead to changes in density which are responsible for the inevitable deformation of the upper, near-surface portion of the Earth's shell. V.V. Belousov's hypothesis, widely accepted in the USSR, asserts that the fundamental cause of folding is the local heating of matter at a certain depth in the outer part of the shell. Heating causes swelling of the crust and results in its stretching, while subsequent cooling leads to the subsidence and contraction of the crust, and thus to folding.

However, physicochemical changes of matter taking place in spatially limited areas of the Earth's shell are incapable of producing any considerable compression deformations of the crust. This conclusion is borne out by approximate determination of the magnitude of compressive and tensile stresses generated, for instance, in the roof of a magmatic chamber (i.e., in the case of the most reliably known alternations in the aggregate state of the shell). For an approximate determination of the rise in subcrustal pressure caused by the fusion of the shell substance sufficient for irreversible crust deformations, let us assume the fusion of a shell layer located in the interval between 100 km and some very large depth. In this case the 100-km thick exoshell may be compared, without large error, to a thin-walled spherical shell filled with a viscous liquid and subjected to internal pressure. In order to produce irreversible tensile deformations (viz. ruptures and shifts) in this exoshell the tensile stresses must reach the magnitude of its tensile strength.

The tensile strength (and the elastic limit) of the near-surface portion of the shell about 40 km thick has been universally estimated by many geophysicists as having a mean value of about 10^9 dyne/cm^2, which is approximately equivalent to 1.02 ton/cm^2. The strength of the shell in its deeper horizons is estimated at 10^8 dyne/cm^2 and even 10^7 dyne/cm^2. Gutenberg (1949) estimated the strength of the Earth's shell to be 10^9 dyne/cm^2 at a depth of 40—50 km, and approximately 10^7 dyne/cm^2 at a depth of 100 km. According to Jeffreys (quoted by Gutenberg) the strength of the matter constituting the Earth's shell reaches approximately 10^8 dyne/cm^2 at a depth of 600 km. According to Barrell, the strength of the shell near the

Earth's surface is about 10^9 dyne/cm^2, and 10^{10} dyne/cm^2 at a depth of 20 km. The strength decreases in a downward direction, rapidly at first, down to approximately $2 \cdot 10^8$ dyne/cm^2 at a depth of 50 km, and then slowly, reaching about 10^8 dyne/cm^2 at a depth of 100 km and about 10^7 dyne/cm^2 at a depth of several hundred kilometers. The strength of most rocks on the Earth's surface is also approximately 10^9 dyne/cm^2.

Let us determine the minimum increase of internal pressure on the lower surface of the exosphere necessary to generate irreversible tensile deformations, assuming that the strength of the exosphere (a shell 100 km thick) is 1 ton/cm^2. The radial and tangential tensile or compressive stresses in a thin-walled spherical shell are proportional to the product of the pressure on the lower surface of the shell and the radius (i.e., the distance from the center to the median surface of the thin-walled shell under consideration) and inversely proportional to twice its thickness.

Let us determine the difference between the internal pressure and the weight of the thin-walled shell, assuming its mean radius to be $632 \cdot 10^6$ cm and the critical tensile stress in its latitudinal and meridional sections 10^3 kg/cm^2. The result is approximately 31.7 kg/cm^2. Consequently, a 31 kg/cm^2 excess of the subcrustal pressure over the weight of the crust (i.e., the exosphere) 100 km thick is critical, and its further increase would generate irreversible tensile deformations in the exoshell. Such a rise in the subcrustal pressure would increase the radius by approximately 3.1 km.

Assuming that the volume of the shell is increased by approximately 10% by its fusion, it follows that the thickness of the molten layer should be approximately 31 km in order to increase the pressure on the roof of the molten layer by the critical value of 31.7 kg/cm^2 (over the internal pressure already existing at this depth).

Let us now determine the approximate scale of the tensile deformations of the exosphere having the same thickness (100 km), e.g., by assuming that the area of the magmatic chamber underneath is approximately $3.14 \cdot 10^4$ km. In order to simplify the calculations we shall assume a cylindrical magmatic chamber with an internal radius of 100 km and a height (thickness) of 31 km. For infinitely thick cylinder walls the stresses of radial compression and tangential tension are equal to the product of the excess of the internal over the external pressure and the square of the inner radius of the cylinder divided by the squared radius of the surface inside the cylinder wall for which the stress is being determined.

Near the inner surface of the cylinder wall the maximum compressive radial stress (equal to the difference between the internal and the external pressures) reaches 31.7 kg/cm^2. At a distance of approximately 17 — 18 km from this surface the radial compressive stress and the tangential tensile stress are approximately equal to the strength of the substance at the respective depth. At a distance of 177 km the magnitudes of both stresses amount to only one-tenth of the strength of the shell, i.e., they may be considered to be negligible. The tensile stresses in the roof of the magmatic chamber can be approximated with the aid of the formulas for the determination of stresses in uniformly loaded plates fixed along the entire edge.

According to calculations, the radial tensile stress near the contour reaches a magnitude of about 23.6 kg/cm^2, i.e., only 1/25 — 1/40 of the

tensile strength of the roof, while the tangential tensile strength in the roof is approximately 5.9 kg/cm^2 (1/100 — 1/160 the tensile strength of the roof).

The maximum sag of the roof is approximately 36.1 cm.

Thus, the tensile stresses in the roof of the magmatic chamber of the above dimensions as well as its sag are insignificant in comparison with its strength, and are capable of generating only elastic deformations of the roof. The tensile stresses in the roof will equal the roof's tensile strength only when the radius of the magmatic chamber is approximately 480—650 km. In this case the maximum sag of the roof will be 190—640 m. Such dimensions of magmatic chambers may be regarded as critical, their further increase would facilitate the generation of irreversible deformations of the roof.

In the case of the solidification of the molten matter in a magmatic chamber of critical dimensions the inward sag of the roof will be too small to generate substantial compressive crustal deformations. Obviously, compressive crustal deformations in large areas entail physicochemical changes of matter in very extensive magmatic chambers in the shell, and possibly even throughout the entire geosphere. It is quite probable that such alterations in the state of matter of an entire shell layer (e.g., its fusion) may have occurred in the recent past history of the Earth. Investigations into the Earth's thermal history made by several scientists have revealed that the decay of radioactive elements in the bowels of the Earth following its formation caused its progressive heating; the fusion of a thick layer within the shell took place at a certain stage of this heating at a particular depth below its surface.

In the USSR painstaking investigations of the Earth's thermal history and temperature were conducted by Lyubimova over many years (1955, 1956, 1957, and 1958). In her various studies she inevitably concluded that the shell substance fused at some depth between 100 and 700 km. According to Lyubimova's calculations the fusion of a layer 600 km thick within the shell would have increased the Earth's radius by approximately 50 km.

Obviously, fusion proceeded slowly, in parallel with the accumulation of the radiogenic heat inside the Earth. Initially fusion must have taken place in a thin layer at a depth exceeding 100 km, with the thickness of the molten layer subsequently increasing with the increasing radiogenic heat in both directions — toward depths exceeding 100 km, with the thickness of the layers. Fusion in the outer layers must have ceased upon reaching a certain maximum thickness corresponding to the maximum concentration of radiogenic heat in the bowels of the Earth. This was followed by the cooling of the outer layers of the Earth's shell as a result of the loss of heat through continuous radiation into space. In the deeper layers the fusion may have continued for some time, gradually decreasing with the depletion of the radioactive elements and the corresponding decrease in internal heat. This cooling, which started in the outer layers, must have spread progressively downward.

In its first stages this propagation of solidification may have been fully compensated by the increasing thickness of the molten layer in the downward direction. Subsequently this compensation must have been superseded by a gradual decrease in the thickness of the molten layer, the rate of its solidification on top being higher than the rate of the downward propagation of fusion. Finally, with further depletion of the radioactive elements, slow solidification must have taken place throughout the entire

molten layer. Many Soviet and non-Soviet geophysicists contend — on the basis of the unimpeded propagation of transverse seismic waves throughout the entire shell, including the Earth's core — that this shell is now in the solid state and may contain only isolated molten "oases".

The possible existence of a molten layer in the outer portion of the Earth's shell in the recent geological past is consistent with geological observations that have revealed the following: 1) the extensive occurrence of magmatic chambers over the Earth and huge amounts of effluent lavas on the Earth's surface; 2) repeated intrusions and extrusions of magma in the same areas, often separated by considerable periods of time, of the order of magnitude of tens of millions of years, while the total duration of magmatic activity in these areas reached hundreds of millions of years.

According to Lyubimova, many geophysical observations seem to indicate the existence of a differentiated, molten layer with acid rocks concentrating in the outer portion and rocks with a higher content of iron having sunk toward the base. Simultaneously a redistribution of radioactive elements took place, with enrichment in the upper acid rocks and depletion in the lower strata. This must have increased the temperature gradient in the so-called waveguide layer whose presence has been established by geophysicists at a depth of about 150 km (in strata with lower seismic wave velocity), and decreased the temperature gradient at the base of the "differentiation zone". The base of this zone coincides with the so-called "C-layer", with high seismic wave velocities and a jump in electrical conductivity, found by geophysicists to exist at depths of 600 to 900 km.

Lyubimova's calculations indicate that the temperature gradients are precisely those which are required for the observed variation in seismic wave velocities. According to Lyubimova, the concentration of iron due to the differentiation of matter in the lower portion of the molten layer (which she designated "differentiation zone") "is capable of increasing the electrical conductivity at these depths, analogous to the case of several silicate glasses which usually possess low ionic conductivity, but which acquire high electronic conductivity in the presence of iron impurities" (1958).

The fusion and subsequent solidification of a thick layer within the shell, which caused alternate extension and contraction of the Earth's radius, a protracted increase of the radius due to the thermal expansion of the inner portions of the Earth, as well as possible changes in the length of the radius due to other transformations of matter, inevitably generated deformations in the outer part of the shell. While ascribing due importance to variations in the physicochemical state of matter inside the Earth, it cannot be denied that variations in the Earth's rotation must have played an important part in the deformations of the outer portion of the shell. Variations in the Earth's volume (within limits) do not provide any convincing explanation for many characteristics of the deformations of the Earth's crust, such as their periodic formation and their geographical distribution.

Indeed, an explanation of the fairly regular periodic formation of extensive folded structures requires the assumption of regular periodic variations in the liberation and accumulation of radiogenic heat inside the Earth, or of regular periodic variations in the outflow of heat toward the Earth's surface. However, such assumptions are improbable, since radioactive elements decay at a constant rate which is independent of temperature and

pressure. The assumption of other cyclic variations in the state of matter, similar to harmonic oscillations, is also of low probability. Even if they did exist, it would be very difficult to provide a convincing explanation for the formation of extensive folded zones in certain geological periods being limited to the polar regions, with the equatorial regions being devoid of their age analogues. It is also difficult to explain why the formation of folded structures in the polar regions was accompanied by synchronous tensile deformations of the Earth's crust in the equatorial regions, accompanied by faults, nonuniform radial uplifts, and profuse fissure eruptions mainly of basic magma. For example, the Upper Carboniferous—Lower Permian folded structures of the Urals and the Upper Latians have neither direct continuations in equatorial regions nor submeridional age analogues. The extensive Upper Cretaceous—Lower Tertiary submeridional folded structures of northeastern USSR and of the Rocky Mountains of North America similarly have neither a direct continuation nor age analogues in the equatorial regions.

Solidification of the molten layer in the shell must have caused crustal compressive deformations of submeridional strike extending from the North to the South Pole, such as in the shape of stepped folded structures, as well as sublatitudinal folded zones around the entire Earth. Such structures could not have been missed by geological observations even if they represented only marginal formations around intact crust fragments which had not undergone compressive deformations.

The contraction of the Earth's surface caused by the contraction of its volume and, consequently, of its radii, must be accompanied by a simultaneous decrease in the length of parallels and meridians.

Great difficulties are encountered in attempts to explain, with the aid of assumed variations in the Earth's state of aggregation, the possibility and cause of the formation, during the same geological periods, of compressive deformations in the polar regions and of tensile deformations in the equatorial regions. However, this actually happened in the Upper Cretaceous—Lower Tertiary period when folding occurred in northeastern Eurasia and in North America, while India, Africa, and the Indian Ocean bottom were undergoing tensile deformations accompanied by the formation of numerous vertical or near-vertical faults obviously caused by tensile, rather than compressive stresses in the crust; tremendous extrusions of magma flowed from the fissures formed by these faults.

It is impossible to provide a plausible explanation of the alternating expansion and compression of the crust in the same fragment based solely on the physicochemical changes in matter. Alternations of this kind are known, for example, in the northeastern regions of the USSR and in the North-American Rocky Mountains. During the Triassic, Jurassic, and Lower Cretaceous periods the Earth's crust in these regions underwent tensile deformations accompanied by the formation of numerous long, steeply inclined, and even vertical faults of submeridional strike with intrusions and eruptions of magma mostly of basic and intermediate composition. In the Upper Cretaceous the same regions underwent folding processes which were, in turn, superseeded by tensile processes in later periods, including the Quaternary; these tensile deformations caused faults accompanied by differentiated radial uplifting of crust blocks and by fissure eruptions of magma. The difficulties involved in interpreting the causes of the above events are eliminated by assuming that the crustal

deformations were caused by the simultaneous effect on the crust of deforming forces generated by physicochemical changes in the matter, and by long-period variations in the Earth's rotation.

At the present time three types of variations in the Earth's rotational velocity are reliably known (Pariiskii, 1954). These are long-period (secular) variations, short-period variations (which include variations with cycles of 24 hours, half a year, a year and 14 months), and irregular discontinuous variations.

The tensile or compressive stresses generated in the shell by the short-period and the irregular variations in the Earth's rotation are much less than the tensile or compressive strength, and consequently they do not produce irreversible deformations of the Earth's crust; therefore we are not concerned with them. On the other hand, long-period variations in the Earth's rotation may cause the buildup of compressive and tensile stresses in the outer part of its shell, exceeding the tensile and compressive strength of the latter and generating irreversible deformations. We shall examine these variations more closely.

Comparison of observations of solar eclipses in ancient times performed by Greek, Babylonian, Chinese, and Egyptian astronomers with modern astronomic calculations reveals beyond doubt a decrease in the angular velocity of the Earth's rotation over the last 2000 years, as a result of tidal friction. Furthermore, it has been established by several scientists that the deceleration of the Earth's rotation is subtracted from its acceleration; the latter is due to physicochemical variations of matter inside the Earth, and is therefore unrelated to tidal friction. In the USSR this problem was thoroughly investigated by Pariiskii (1945, 1948, 1953, and 1954), who demonstrated that the deceleration of the Earth's rotation over the last 2000 years due to tidal friction resulted in an average increase in the diurnal period of $23 \cdot 10^{-6}$ sec/year. This increment comprises an increase of $33 \cdot 10^{-6}$ sec/year due to the deceleration caused by tidal friction, and a decrease of $1 \cdot 10^{-5}$ sec/year which is obviously due to physicochemical variations of matter inside the Earth.

If the diurnal period had been increasing even by such a small quantity as $33 \cdot 10^{-6}$ sec/year, (or even $23 \cdot 10^{-6}$ sec/year) but over a very long period, such as approximately 3 —4 billion years, the rotational velocity of the Earth would have decreased to a value at which the stresses in its shell would exceed its strength by many times, resulting in a rearrangement of the Earth's configuration so as to re-establish the disturbed equilibrium. There would have been considerably less flattening of the poles and the figure of the Earth would have more closely approximated a sphere. As will be seen below, a decrease in the polar flattening of the Earth would be closely related to deformations in the outer portion of its shell. The shell's outer portion would undergo compressive deformations (such as folding or overthrusts) in the equatorial regions, and tensile deformations (such as domed swells, troughs, or faults) in the polar regions.

According to the universally accepted tidal theory originated by G.H. Darwin (1923) and subsequently modified by H. Jeffreys (1960 and earlier works), approximately four billion years ago the Earth and the Moon were separated by only a very short distance of about 15,000 km. At that time the velocity of revolution of the Moon and the rotational velocity of the Earth were considerably higher than they are now, about $3.90 - 4.36 \cdot 10^{-4}$ sec^{-1}. Tidal friction has decreased the angular velocity

of the Earth's rotation to its present value of $0.7292 \cdot 10^{-4}$ sec^{-1}. It will be appreciated that such a considerable decrease in the rotational velocity of the Earth (by a factor of 5.3—6) must have inevitably transformed the Earth's figure causing conjugated crustal deformations on a tremendous scale.

Recently E.A. Ruskol advanced a hypothesis on the origin and evolution of the Moon based on the principles of O. Yu. Shmidt's theory of the origin of the solar system. According to Ruskol's hypothesis (presented at the Moscow Astronomic-Geodetic Society on 10 February 1961), the Moon was formed from particles of the protoplanetary cloud soon after the formation of the Earth, at a distance of about 5—10 terrestrial radii from the latter. At that time the velocities of the revolution of the Moon about the Earth and of the Earth's rotation were considerably higher than they are now. Subsequently both velocities decreased continuously because of tidal friction, down to their present-day values. The majority of scientists engaged in determining the Earth's age date the Earth's formation as 4.5—5 billion years ago; if this is correct the Moon could not have been formed more than four billion years ago.

According to the Darwin—Jeffreys tidal theory, the angular velocity of the Earth's rotation must have been higher than the angular velocity of the Moon's revolution about the Earth in order that the tidal friction could decelerate the Earth's rotation and accelerate the Moon's revolution about the Earth (so that the Moon must increase its distance from the Earth, the velocity of its revolution eventually decreasing again). Shternfeld (1958) calculated that if the distance between the Earth and its satellite is equal to five terrestrial radii (about 31,850 km), the satellite must have a tangential velocity of revolution of 3.538 km/sec; if the distance is equal to ten terrestrial radii (about 63,700 km), the velocity must be 2.502 km/sec. Consequently, assuming that the Moon was formed at a distance of 63,700 km from the Earth, we must also assume that the angular velocity of the Moon's revolution about the Earth must have been approximately $0.4 \cdot 10^{-4}$ sec^{-1} in the initial stages. If it is assumed that the Moon was formed at a distance of 32,000 km from the Earth, the initial angular velocity of the Moon's revolution must have been approximately $1.111 \cdot 10^{-4}$ sec^{-1}.

According to the first assumption, the mean variation in the Moon's angular velocity over a period of $4 \cdot 10^9$ years would have been about $0.093 \cdot 10^{-13}$ sec^{-1} per year, which is only half of the present rate of decrease of approximately $0.19 \cdot 10^{-13}$ sec^{-1} per year. However, this is inconsistent with the tidal theory, since the intensity of tidal friction is inversely proportional to the sixth power of the distance between the mutually attracted bodies and is almost directly proportional to the squared velocity of the propagation of the tidal wave. Consequently, the initial velocity of the Moon's revolution around the Earth shortly after the Moon's formation must have been considerably higher than $0.4 \cdot 10^{-4}$ sec^{-1}, and its distance from the Earth must have been considerably less than 10 terrestrial radii. On the second assumption the mean decrement of the Moon's revolution velocity over a period of four billion years would be $0.27 \cdot 10^{-13}$ sec^{-1} per year, i.e., slightly larger (by a factor of 1.4) than the present-day decrement.

Thus, Ruskol's hypothesis was found to be the most probable one. According to this hypothesis the Moon was formed at a distance of almost

five terrestrial radii from the Earth, i.e., about 31,800 km, while the angular velocity of the Moon's revolution was approximately $1.2 \cdot 10^{-4}$ sec^{-1}.

In addition to the friction generated by lunar tides, the Earth is affected by the friction resulting from solar tides. It is the consensus among astronomers that the friction of the solar tides has decreased the angular velocity of the Earth's rotation, the decrement in the past being essentially the same as that prevailing at the present time, since there has been very little change in the distance between the Sun and the Earth. According to computations performed by G.H. Darwin (1923), the ratio between the present rotational deceleration of the Earth due to the friction of the solar tides and its total deceleration due to both lunar and solar tides is approximately 1 : 3.2, the total deceleration having been approximately $0.28 \cdot 10^{-13}$ sec^{-1} per year on the average over the last 2000 years. Consequently the present-day deceleration of the angular velocity of the Earth's rotation due to solar tides amounts to about $0.875 \cdot 10^{-14}$ sec^{-1} per year, totalling $0.35 \cdot 10^{-4}$ sec^{-1} over the period of four billion years.

If the mean variation in the Earth's rotational velocity had remained the same as it is now over the four-billion year period, contrary to the tidal theory, the lunar tides over this period would have accounted for the decrease in the Earth's rotational velocity by approximately $0.76 \cdot 10^{-4}$sec^{-1}. Under these conditions the angular velocity of the Earth's rotation immediately following the formation of the Moon should have been $1.85 \cdot 10^{-4}$ sec^{-1}, but it has already been noted that this condition is incompatible with the tidal theory. According to this theory the difference between the velocities of the Earth's rotation and the Moon's revolution must have increased progressively to a maximum beyond which it should have decreased, rapidly at first, and then at a steadily diminishing rate.

At the present time the variation in the velocities of the Earth's rotation and the Moon's revolution is closer to the latter stage, so that the mean variation in the Earth's rotational velocity over the four billion years must have been many times larger than it has been over the last 2000 years. Consequently (in accordance with the tidal-friction theory) the angular velocity of the Earth's rotation in the period immediately following the formation of the Moon must have been considerably higher than $1.85 \cdot 10^{-4}$ sec^{-1}.

There is no doubt that the long-period decrease in the Earth's rotational velocity caused by the thermal expansion of the Earth must be added to the above-mentioned long-period variation in the Earth's rotational velocity caused by tidal friction. It was calculated by Lyubimova (1958) that three billion years ago the average annual increment of the Earth's radii due to internal heating amounted to 0.01 — 0.005 cm. The current radial increase is approximately 0.001 cm/year, and this must cause a corresponding increase of the diurnal period and a decrease in the Earth's polar flattening, accompanied by deformations of the crust.

In addition to the long-period variations, the Earth's rotational velocity also undergoes variations having shorter cycles which are superimposed on the longer ones. These short-period variations include those caused by global phenomena, such as glaciation or considerable warming of the climate, to which the Earth was repeatedly subjected in the past, as confirmed by geological observations. The accumulation of ice and snow in the polar regions during glaciation periods decreases the moment of

inertia of the Earth, thereby increasing its rotational velocity in accordance with the law of conservation of angular momentum.

On the contrary the ablation of ice and snow in the polar regions during the warmer periods increases the Earth's moment of inertia, thereby decreasing its rotational velocity according to the same law. Obviously, such variations in the Earth's rotation do not reach magnitudes large enough to generate critical stresses in the Earth's shell. Most probably the related crustal deformations are elastic, or at any rate small-scale deformations. On the other hand, they must shift the surface gradients, thereby shifting the shore lines of seas and lakes as well as the river beds.

The long-period variations in the Earth's rotation are combined with variations produced by differentiation of the terrestrial matter, including differentiation of the substance of the outer shell in the depth interval of 100—700 km (where, according to Lyubimova, the matter has fused and solidified), possible phase transformations of matter, and other factors.

Deceleration of the Earth's rotation by a factor of 2.6—3 and possibly more would cause a correspondingly large decrease in its polar flattening (from approximately 1/40 to its present value of 1/298). This transformation of the figure of the Earth would generate closely related large-scale compressive deformations of the Earth's crust in the equatorial region, and tensile deformations in the polar regions. These crustal deformations would add to the tensile deformations generated by the thermal expansion of the Earth's radius, which were very large, especially in the more remote past. According to Lyubimova, the thermal expansion of matter inside the Earth would increase its radii by 90—165 km over a period of three billion years. Such a large radial extension would have generated considerable tensile stresses in the outer portion of the Earth's shell which would have certainly developed faults. Over this period, the length of the equator should have increased by approximately 560—1030 km, while the length of the parallels should have increased by 485—875 km at a latitude of 35°, by 373—799 km at 50°, by 281—517 km at 60°, by 236—435 km at 65°, and by 194—355 km at 70°. The elongation of meridians must have nearly equaled the maximum elongation of the equator (which was approximately 559—1028 km). The total increase in the length of the parallels due both to the change in length of the terrestrial radii (caused by the decrease of polar flattenings), and to thermal expansion would be as follows. The equator would increase by approximately 240—710 km in length, and the parallels by 485—875 km at a latitude of 35°, 530—955 km at 50°, 480—715 km at 60°, 430—630 km at 65°, and 370—530 km at 70°.

The meridians would increase by approximately 721—1190 km. To these tensile deformations in the outer part of the Earth's shell would be added the tensile deformation due to the fusion of substance in a layer about 600 km thick. According to Lyubimova's calculations, the resultant elongation of the radii should have been 50 km.

Thus, over the entire period of about four billion years the Earth's crust must have been subjected to continuous tensile stresses and faulting both in the polar and the equatorial regions. The stresses and faults must have been especially great in the first half of this period, but considerably less pronounced during the last stages of the geological history of the Earth. Consequently, the Earth's surface should not be carrying any large,

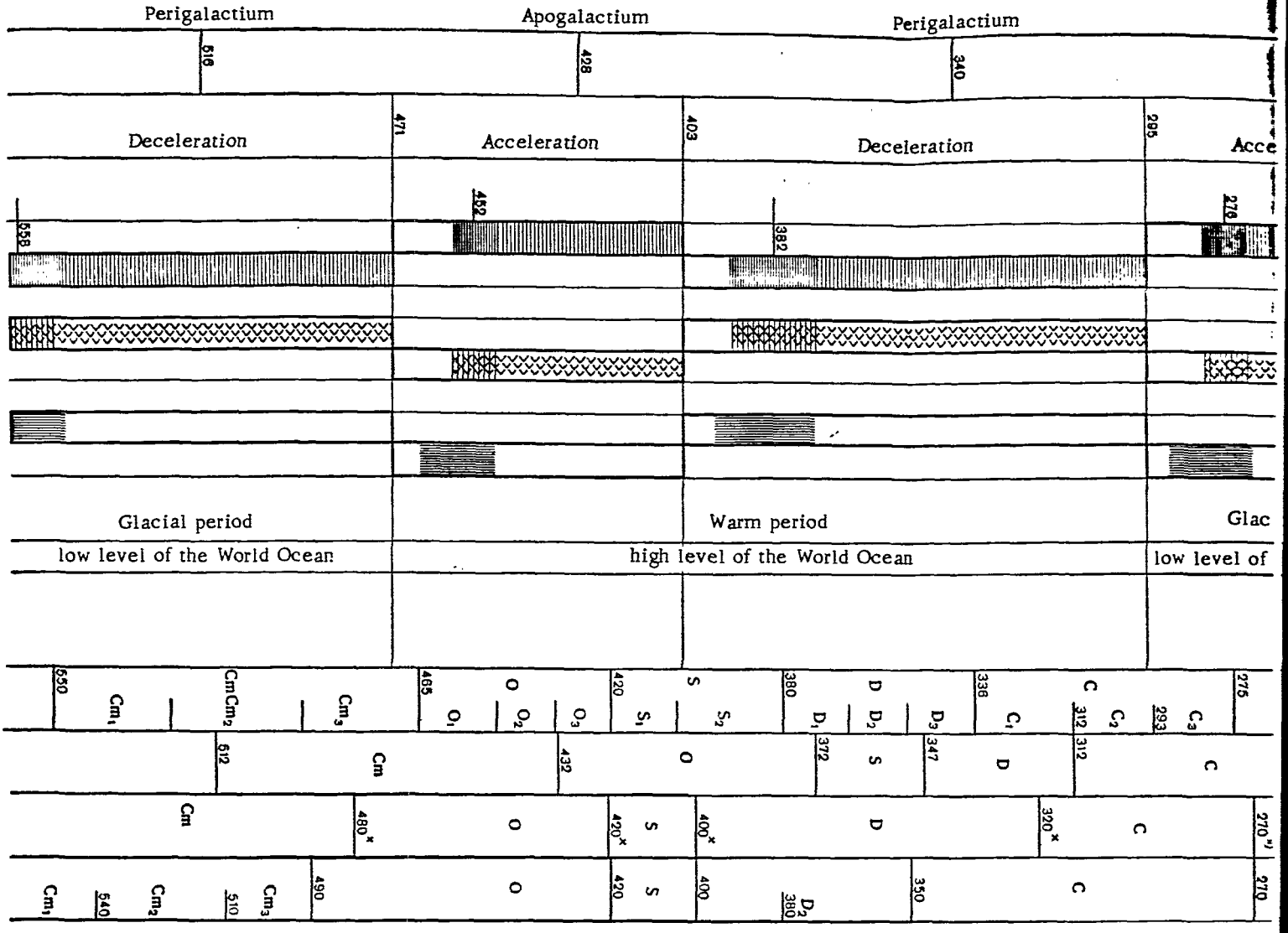
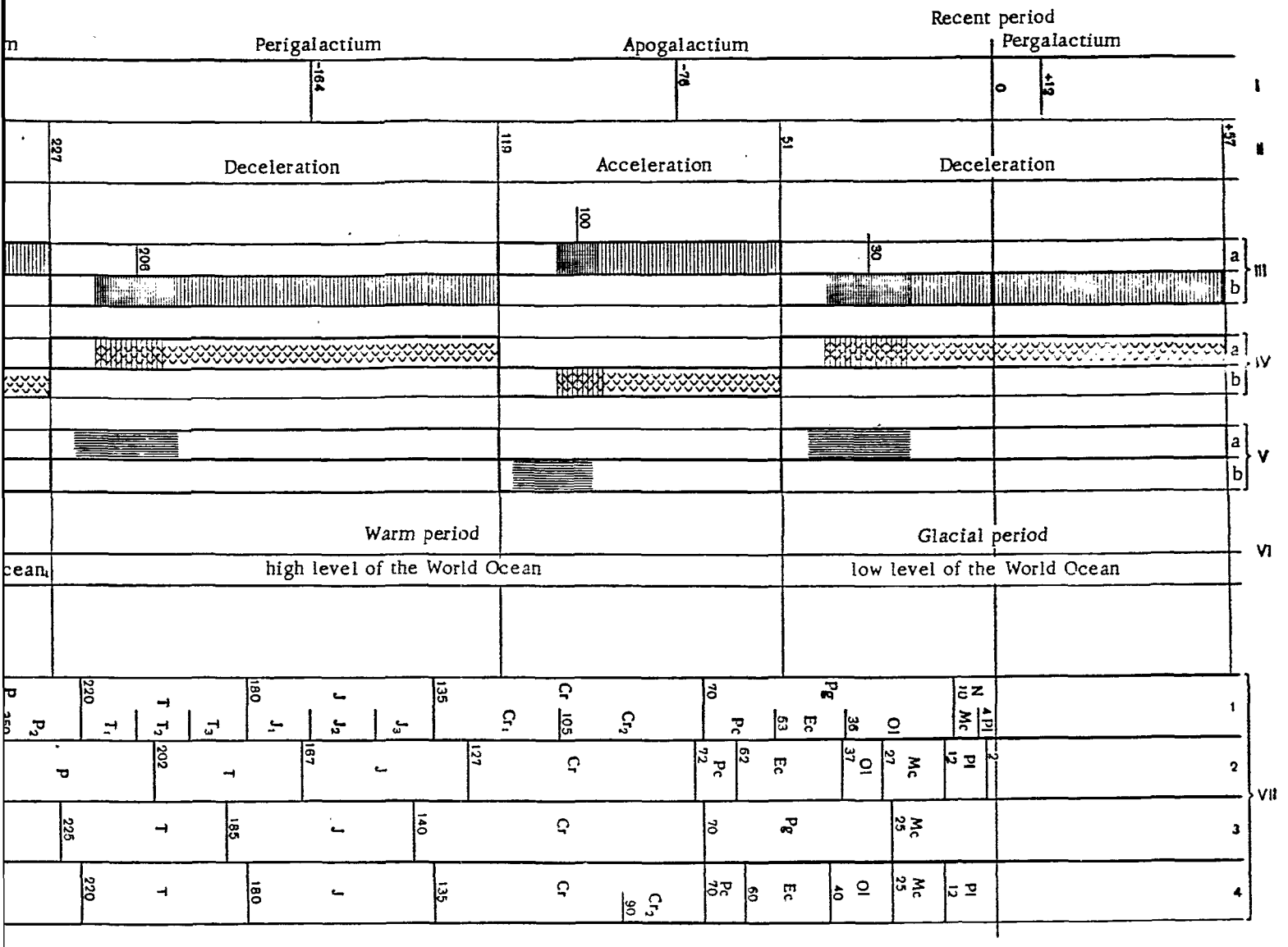


FIGURE 1. Comparison of the periodic variations in the velocity of the galactic movement of the solar system and the Earth's rotatior logical tables:

I. anomalistic periods of the Sun's revolution in the Galaxy (millions of years); II. periods of the variation in the rotational velocit marks period of most intense deformations while light shading marks repeated deformations with quiescent periods; IV. tensile defor equatorial regions. Shading indicates the approximate period of the most intense faulting and magmatic eruptions; ticks indicate per polar regions; b. in the equatorial regions. Shading marks the periods of most intensive transgressions; VI. general climatic variatic 1. according to Polevaya, 1961; 2. according to Kay (and Holmes), 1951 (accepted in the USSR since 1960, Tugarinov), with the cr



as well as the periodic deformations of the Earth's crust and certain other geological events, with the geochrono-

f years); III. compressive deformation of the Earth's crust (folding, wrench faults, and overthrusts); heavy shading
e Earth's crust (faults and shifts accompanied by profuse magmatic eruptions) — a. in the polar regions; b. in the
ted faulting and magmatic eruptions separated by quiescent periods (epochs); V. marine transgressions — a. in the
periods and warm periods; low and high levels of the World Ocean; VII. geochronological scale, (million years):
g the upper limits; 3. [missing in Russian original]; 4. according to Kulp, 1960.

A similar value for the polar flattening of the Earth (1 : 297.6) was obtained by calculations based on the conditions of its hydrostatic equilibrium. Consequently, the present state of the Earth is in fact extremely close to that of hydrostatic equilibrium. Therefore, throughout its existence, the Earth's hydrostatic equilibrium, disturbed by variations of its rotational velocity, was restored by repeated transformations of its figure in accordance with the above law for the transformation of the form of an ellipsoid by variations of its polar flattening.

Physically, changes in the Earth's figure are explained as follows: a variation of the Earth's rotational velocity inevitably changes the centrifugal forces acting on every unit of mass; the equilibrium between the centrifugal forces and the centripetal forces produced by the attraction of mass elements toward the Earth's center is thus broken. The changes in centrifugal force are considerably more pronounced in the equatorial than in the polar regions, and this difference enhances the mass imbalance. A decrease in the Earth's rotational velocity and the corresponding decrease in the centrifugal forces causes a considerably larger increase in the centripetal acceleration of the mass elements in the equatorial region than it does in the polar regions. This disparity generates compressive stresses in the shell which are considerably stronger in the equatorial region than in the polar regions.

When the difference between these stresses reaches the compressive strength of the shell and exceeds it, the shell's endosphere undergoes plastic deformations, with matter flowing from the equatorial to the polar regions. The equatorial region of the shell's exosphere (crust) undergoes irreversible compressive deformations, while tensile deformations occur in the polar regions. These deformations in the endosphere and exosphere of the shell restore the equilibrium of the Earth's figure. If the centrifugal forces varied identically per unit mass at all latitudes, the transformation of the Earth's figure with reduced rotational velocity would merely involve a slight uniform compaction of its substance and a corresponding decrease of its volume; in the case of increased velocity, the density would decrease slightly while the volume would be slightly increased, but there would be scarcely any variation in the polar flattening.* It is clear that the variation of the centrifugal forces at the critical parallels due to changes in the Earth's rotational velocity is always equal to the mean variation of centrifugal forces over the entire surface of the Earth.

Needless to say that actually the Earth's crust is not fixed at the critical parallels, and a decrease in the velocity of the Earth's rotation may always cause a slight meridional shift of the crust together with the subcrustal masses toward the poles.

However, even these slight shifts of the crust along the meridians (conforming to the slight variations in the length of the meridional arcs and their curvatures) would be strongly limited by the necessity for a considerable preliminary (or simultaneous) latitudinal contraction of the crust and its radial subsidence in the equatorial region. The preliminary buildup of compressive stresses necessary for the latitudinal contraction of the crust in this region significantly impedes any (even slight) shift of the crust along the meridians and its transformation

* There would still be a slight variation of the polar flattening as a result of the slight variation in the Earth's moment of inertia.

toward the new equilibrium profile. An increase in the Earth's rotational velocity cannot cause crustal shifts along the meridians (with the exception of small local shifts along shear surfaces) because of the necessary contraction of the meridians in their entirety (the contraction being larger in the polar regions). An increase in the polar flattening will cause a considerable contraction of the Earth's crust in the polar regions along the parallels; this contraction necessitates a buildup of considerable compressive stresses, and therefore the rearrangement of the crust toward the new equilibrium profile will occur at some time later than (or at least simultaneously with) the commencement of the deformations involved in the latitudinal and meridional extension of the crust in the equatorial region.

Thus, with a decrease in the polar flattening (which is tantamount to a decrease in the Earth's rotational velocity) the Earth's crust in the equatorial region undergoes deformations of latitudinal and meridional contraction (the latter occurring predominantly in the latitudinal zone near the critical parallels), accompanied with radial subsidences; the Earth's crust in the polar regions undergoes latitudinal and meridional tensile deformations accompanied with radial upliftings. An increase of the polar flattening (and rotational velocity) of the Earth causes tensile latitudinal and meridional deformations of the Earth's crust in the equatorial region accompanied with radial upliftings, while the crust in the polar regions undergoes compressive latitudinal and meridional deformations accompanied with radial subsidences.

By the properties of ellipsoids the crust undergoes larger deformations in the latitudinal direction, since a variation of the polar flattening (i.e., its decrease or increase) causes a considerably larger variation in the length of the parallels than in the length of the meridional arcs between them. Therefore the meridional compressive deformations of the crust must be the more pronounced in the case of increased velocity of the Earth's rotation in the polar regions, and in the case of its decrease in the equatorial region. In both cases folding deformations must occur near the critical parallels, and therefore folded structures of latitudinal strike near the critical parallels will be polygenetic and highly complex.

There is no doubt that an increase in the Earth's rotational velocity in the polar regions or its decrease in the equatorial region may also produce folded structures fringing the stable crustal fragments that have escaped compressive deformations (in both latitudinal and meridional directions). Wherever variations in the Earth's rotation during the given period generate tensile stresses accompanied with radial upliftings (due to the influx of subcrustal plastic masses), tensile deformations of the crust occur, together with large-scale fissure extrusions of magma. Belts and zones of compressive and tensile deformations are produced in the less stable, weakened areas of the Earth's crust, with nonuniform composition and structure.

The above estimates of the strength of the Earth's shell make it possible to assess the minimum variation in the Earth's rotational velocity that is necessary for the compressive and tensile stresses in the outer portion of the shell (the exosphere) to exceed the shell's elastic limit (with respect to its compressive and tensile strength). According to calculations, this minimum variation in the Earth's rotation must be approximately $0.06 - 0.1 \cdot 10^{-4}\,\mathrm{sec}^{-1}$. On reaching this magnitude, variations in the Earth's

rotation will generate irreversible compressive and tensile deformations of the Earth's crust and a transformation of the Earth's figure. Such variations in the Earth's rotation will be the combined result of all the partial variations, and they will be of at least a certain minimum duration. Apparently there have been prolonged increases in the Earth's rotational velocity alternating with prolonged decelerations.

In all probability, large-scale folding of the crust in the polar region (such as the Urals, the Appalachians, the folded structures in northeastern USSR, the Rocky Mountains, the Cordilleras, and others) was preceded by a period of prevailing increase in the Earth's rotational velocity. On the other hand, tensile formations of the Earth's crust (occurring on a very large scale in the polar regions), accompanied with faults, nonuniform radial uplifts of individual fragments, subsidences and swellings, as well as with injection and profuse eruptions of magma into and through the fault fissures (mainly basic magma) were preceded by periods of prevailing deceleration of the Earth's rotation. Obviously, these tensile and compressive crustal deformations generated by significant variations in the Earth's rotation played an important part in the transformation of the outer portion of the Earth's shell, even when being greatly complicated by simultaneous crustal deformations resulting from physicochemical variations of the matter inside the Earth. Therefore traces of these deformations manifest themselves fairly distinctly on the surface.

The Devonian geological period was probably characterized by prevailing deceleration of the Earth's rotation. Possibly such deceleration had begun as early as the Silurian and terminated in the Upper Carboniferous. This period of the assumed deceleration of the Earth's rotation occupies an intermediate position between the Caledonian and the Urals (Hercynian) folding in the polar regions. This hypothesis is based on the absence of any appreciable Upper Silurian—Lower Carboniferous folded structures of submeridional strike* in the polar region, and on the presence of an extensive fault zone on the eastern slope of the Urals manifesting itself in numerous porphyrite dikes as well as in large meridional intrustions of peridotites, pyroxenites, and gabbros of the Northern and Central Urals and in other regions.

An increase in the Earth's rotational velocity apparently commenced in the first half of the Carboniferous period, and its prevalence led to the formation of the folded structures of the Urals in the second half of the Carboniferous period and of the Appalachian folded structures in the Upper Carboniferous—Lower Permian period.

This was apparently again followed, in the Permian period, by a deceleration of the Earth's rotation which led to a tensile deformation of the crust at the end of the Permian and the beginning of the Triassic in the polar regions, on the Siberian platform, accompanied with faults and profuse fissure eruptions of basic magma (the Siberian traps). The tensile deformation of the Earth's crust continued throughout the Triassic, Jurassic, and

* The reader is reminded that the decrease in the length of the parallels in the polar regions associated with an increase in the velocity of the Earth's rotation is considerably larger than the decrease in the length of the meridian arcs, and therefore in these regions folded structures of submeridional strike must prevail over those of latitudinal strike. The increase in the length of the parallels associated with a decrease in the velocity of the Earth's rotation is likewise larger than the increase in the length of the meridional arcs.

Upper Cretaceous periods, involving various areas in the polar region. Its traces have been preserved in the extensive fault zones which are interlaced by dikes of porphyrites and porphyries, as well as in fields of basalt and andesite eruptions in northeastern USSR, in the Cordilleras, in the Rocky Mountains, and elsewhere. The tremendous scale of the tensile crustal deformation in northeastern USSR is evidenced by the large troughs, the numerous steeply dipping and fairly thick dikes of porphyrites and porphyries occurring over very extensive areas, the long, narrow belts of effusives (traces of fissure eruptions), the nonuniform radial uplifts of individual crustal fragments, etc.

Acceleration of the Earth's rotation was apparently again prevalent at the beginning of the Upper Cretaceous period, resulting in the formation of folded structures in northeastern USSR, in the Cordilleras, and in the Rockies, and to the formation of tensile deformations and faults of the Earth's crust in the equatorial region — in Africa, and India, in the northern Indian Ocean, and probably also in South America. These tensile deformations and faults of the crust were accompanied with intrusions of basic magma into numerous fissures (e.g., in Africa) and with large-scale fissure eruptions of basic magma to the surface (e.g., in India, and in the Indian Ocean). In the Cordilleras and the Rockies the folding continued into the Lower Tertiary period.

The prevailing deceleration of the Earth's rotation apparently recurred in the second half of the Tertiary, and has continued to the present time. It generated tensile deformation and faults of the Earth's crust in numerous areas in the polar regions as well as large-scale, mainly fissures eruptions of basic and intermediate magma. Huge fault fissures which served as outlets for the eruption of thick basalt sheets are known in Greenland, Iceland, the northern Atlantic, Bolshezemel'skaya Tundra, Spitsbergen, eastern Transbaikalia, Mongolia, northeastern USSR, Alaska, British Columbia, and other regions. No true folded formations (true crustal folding) on any considerable scale occurred during this period in the polar regions. According to geological observations, the orogenesis in Alaska, the Rockies, and other areas during this period took the form of nonuniform (radial) uplifting of individual crustal blocks between faults, most probably as a result of the tensile deformation of the crust combined with its radial uplifting.

The period between the formation of the folded structures of the Urals and those in northeastern USSR, the Appalachians, and the Rockies lasted approximately 175 to 180 million years. Indeed, the commencement of the most intensive folding processes in the Urals is dated as the end of the Middle and the beginning of the Upper Carboniferous period, while the commencement of the most intensive folding processes in northeastern USSR is dated as the end of the Lower Cretaceous and the beginning of the Upper Cretaceous period. According to the geochronological scale developed by Holmes and Kay (1951), the boundary between the Middle and Upper Carboniferous period lies approximately 265 to 270 million years ago, and approximately 285 to 290 million years ago according to the scale developed by Polevaya (1961); the boundary between the Lower and the Upper Cretaceous period is dated as approximately 90 to 100 million years ago on the former scale, and as approximately 105 to 110 million years on the latter. The period intervening between the folding periods was, therefore, about 175 to 180 million years.

A period of approximately the same duration intervened between the formation of the largest crustal fault zones which was accompanied with large-scale magma eruptions (mainly basic) and the nonuniform uplifting of crustal fragments in the Upper Tertiary—Quaternary and in the Permian—Triassic—Jurassic. Early crustal faults with profuse eruptions of basalts are known in the Lower Eocene of North America (in Washington and Oregon) and eruptions of andesites are known in the Absaroka Mountains in the Rockies and on the Yellowstone Plateau. According to the geochronological scale, these eruptions occurred approximately 40 to 50 million years ago. Early tensile deformations of the crust and fissure eruptions of basic magma during the Early Mesozoic period of deceleration of the Earth's rotation had already commenced by the Upper Permian period, approximately 230 to 220 million years ago on Polevaya's geochronological scale. The intervening period was, therefore, again approximately 180 or 170 million years. This interval between successive periods of compressive deformations of the Earth's crust and those of tensile deformations is very similar to the so-called anomalistic period of the revolution of the solar system about the central galactic masses, determined to be approximately 176 million years by Parenago (1952). This fairly close agreement can hardly be accidental. Evidently, variations in the Earth's rotational velocity are closely related to the nonuniformity of this galactic movement of the solar system.

REFERENCES

BELOUSOV, V.V. Osnovnye voprosy geotektoniki (Main Problems of Geotectonics). — Gosgeoltekhizdat. 1954.

BELOUSOV, V.V. Strukturnaya geologiya (Structural Geology).— Izdatel'stvo MGU. 1961.

BENIOFF, G. Seismic Data on Crustal Structure and Tectonic Activity. [Russian translation. 1957.]

BEZUKHOV, N.I. Osnovy teorii uprugosti, plastichnosti i polzuchesti (Elements of the Theory of Elasticity, Plasticity, and Creep).— Izdatel'stvo vysshei shkoly. 1961.

BONCHKOVSKII, V.F. Vnutrennee stroenie Zemli (Inner Structure of the Earth). — Izdatel'stvo AN SSSR. 1953.

BONCHKOVSKII, V.F. Tolshchina zemnoi kory (Thickness of the Earth's Crust). — Priroda, No. 5. 1945.

BONCHKOVSKII, V.F. and F.D. BUBLEINIKOV. Zemlya, ee figura i fizicheskie svoistva (The Earth, Its Figure and Physical Properties).— Gostekhizdat. 1956.

BRIDGEMAN, P.W. Physics of High Pressures. — G. Bell, London. 1931. [Russian translation. 1948.]

BUCHER, W. Experiments and Ideas Concerning the Nature of Orogenesis. [Russian translation. 1960.]

DARWIN, G. The Tides and Kindred Phenomena in the Solar System. — Freeman, San Francisco. 1962. [Russian translation. 1958.]

DESITTER, L. Structural Geology. — McGraw-Hill, New York, 1956. [Russian translation. 1960.]

FEDOS'EV, V.I. Soprotivlenie materialov (Strength of Materials). — Fizmatgiz. 1960.

GERT, G. Geology of the Andes. [Russian translation. 1959.]
GORSKII, N.N. Tainy okeana (The Ocean's Mysteries). – Izdatel'stvo, AN SSSR. 1960.
GUTENBERG, B. — In: Collection of Papers "Structure of the Earth's Crust. Continents and Oceans. The Earth's Inner Structure". [Russian translation. 1949.]
GUTENBERG, B. Concerning the Mountains' Roots. [Russian translation. 1949.]
GUTENBERG, B. A Critical Review of the Problem of the Shift of Continents. [Russian translation. 1960.]
GUTENBERG, B. and K. RICHTER. Seismicity of the Earth and Associated Phenomena. — Princeton Univ. Press, New Jersey. 1949. [Russian translation. 1948.]
IZOTOV, A.A. Forma i razmery Zemli po sovremennym dannym (The Earth's Figure and Dimensions According to Modern Data). — Trudy TsNIIGAiK, No.73, Geodezizdat. 1950.
JEFFREYS, H. The Earth, Its Origin, History, and Physical Constitution.— Camb. Univ. Press, Cambridge. 1952. [Russian translation. 1960.]
KAY, M. Sediments and Subsidence in Time. [Russian translation. 1957.]
KING, P. The Evolution of North America. — Princeton Univ. Press, New Jersey. 1959. [Russian translation. 1961.]
KRASOVSKII, A.N. Sovremennye zadachi i razvitie gradusnykh izmerenii (Modern Tasks and Development of Grade Measurements). — Izvestiya AN SSSR, Seriya Geograficheskaya i Geofizicheskaya, No.3. 1941.
LEVANTOVSKII, V.I. Raketoi k Lune (By Rocket to the Moon). — Fizmatgiz. 1960.
LYUBIMOVA, E.A. Termicheskaya istoriya i temperatura Zemli (The Earth's Thermal History and Temperature). — Byulleten' Moskovskogo Obshchestva Ispytatelei Prirody, otdel geologicheskii i geograficheskii, Seriya XII, 7. 1961.
MAGNITSKII, V.A. Osnovy fiziki Zemli (Elements of the Earth's Physics).— Geodezizdat. 1953.
MAGNITSKII, V.A. Geodezicheskie dannye i sostoyanie veshchestv verkhnikh sloev Zemli (Geodetic Data and the State of Substances in the Earth's Upper Layers). — Trudy Soveshchaniya po metodam izucheniya dvizhenii i deformatsii zemnoi kory. Geodezizdat. 1948.
MIKHAILOV, A.A. Kurs gravimetrii i teorii figury Zemli (A Course in Gravimetry and the Theory of the Earth's Figure). — Redaktsionnoe byuro GUGK pri SNK SSSR. 1939.
OGORODNIKOV, K.F. Dinamika zvezdnykh sistem (Dynamics of Stellar Systems). — Fizmatgiz. 1958.
OVCHINNIKOV, A.N. and M.A. GARRIS. Absolyutnyi vozrast geologicheskikh obrazovanii Urala i Priural'ya (Absolute Age of Geological Formations in the Urals and Adjacent Areas). — Opredelenie absolyutnogo vozrasta dochetvertichnykh formatsii. Mezhdunarodnyi geologicheskii kongress, XXI sessiya, Izdatel'stvo AN SSSR. 1960.
PARENAGO, P.P. O gravitatsionnom potentsiale Galaktiki (On the Gravitational Potential of the Galaxy), Part 2. — Astronomicheskii Zhurnal, Vol.29, No.3, Izdatel'stvo AN SSSR. 1952.
PARIISKII, N.N. — Ibid., Vol.22, No.2, 1945.

PARIISKII, N.N. Nepostoyanstvo vrashcheniya Zemli i ee deformatsii (Nonuniformity of the Earth's Rotation and Its Deformations). Trudy Soveshchaniya po metodam izucheniya dvizhenii i deformatsii zemnoi kory. Geodezizdat. 1948.

PARIISKII, N.N. Izmenenie skorosti vrashcheniya Zemli v techenie goda (Annual Variation of the Earth's Rotational Velocity). — In: Sbornik statei "O vliyanii svobodnoi nutatsii Zemli na uglovuyu skorost' ee vrashcheniya". Trudy Geofizicheskogo instituta AN SSSR, No. 19(145), Izdatel'stvo AN SSSR. 1953.

PARIISKII, N.N. Neravnomernost' vrashcheniya Zemli (Nonuniformity of the Earth's Rotation). — Izdatel'stvo AN SSSR. 1954.

PARIISKII, N.N. and O.S. BERLYAND. Vliyanie sezonnykh izmenenii atmosfernoi tsirkulyatsii na skorost' vrashcheniya Zemli (Effect of Seasonal Variations in Atmospheric Circulations upon the Earth's Rotational Velocity). — Trudy Geofizicheskogo instituta AN SSSR, No. 19(146), Izdatel'stvo AN SSSR. 1953.

POLEVAYA, N.I. Shkala absolyutnoi geokhronologii po glaukonitam (Absolute Geochronological Scale by Glauconites). — Voprosy geokhronologii i geologii, Izdatel'stvo AN SSSR. 1961.

RONOV, A.B. and V.E. KHAIN. Devonskie litologicheskie formatsii mira (Devonian Lithological Formations of the World). — In: Sbornik "Sovetskaya Geologiya", No. 41. 1954.

SHTAUB, W. Possibility of Transition from Elliptical Orbit to Circular and Vice Versa. — In: Sbornik statei "Ob iskusstvennom sputnike Zemli", Izd. oboronnoi promyshlennosti. 1959.

SHTERNFEL'D, A. Iskusstvennye sputniki (Artificial Satellites). — Gostekhizdat. 1958.

SYTINSKAYA, N.N. Priroda Luny (The Nature of the Moon). — Fizmatgiz. 1959.

TUGARINOV, A.I. Geologu — o metodakh opredeleniya absolyutnogo vozrasta gornykh porod (Methods for Absolute Dating of Rocks for Geologists). — Gosgeoltekhizdat. 1961.

WANG CHI-TIEH. Prikladnaya teoriya uprugosti (Applied Theory of Elasticity). — Fizmatgiz. 1959.

WILSON, J.T. The Earth's Crust. [Russian translation. 1961.]

ZONN, W. and K. RUDNITSKII. Stellar Astronomy. [Russian translation. 1959.]

G. F. Lungersgauzen

*PERIODIC CLIMATIC VARIATIONS IN THE EARTH'S GEOLOGICAL PAST**

I

Paleoclimatological data occupy a prominent position among new facts and generalizations in the fields of geology, geography, and related sciences. These data are of fundamental interest, and possibly characterize better and more completely (compared with some other more striking discoveries) the current developmental trend of the geological and geographical sciences.

It is characteristic of this trend that investigators working in different branches of science discover that a close interrelationship exists between various facts which appear to be outwardly quite dissimilar, and that these investigators are forced to turn to extraterrestrial, cosmic factors for an explanation of the vast group of phenomena which heretofore were the domain of the geographer and the geologist. In this connection data concerning periodic variations in climate during past geological periods become most important. Analysis of numerous observation and specialized paleogeographic reconstructions concerning deposits of various ages, beginning with Upper Archean and ending with Neogene and Quaternary formations, leads to several inferences which appear to be of fairly general significance. Some of these inferences are presented below.

1. Climatic variations (or fluctuations) were generally synchronous for large areas of the Earth's surface, i.e., they were of a planetary nature.

2. The general regularities of such climatic variations (their duration and trend) have been operative throughout the entire geological history accessible to specialized investigations, probably beginning with the Archean and certainly from the Middle Proterozoic, and continuing until the present time. The facts elicited by geologists and paleogeographers offer no suggestion of any fundamental changes in the general trend of the climatic evolution in the remote geological past in comparison with the thoroughly studied climate of the Anthropogenic or even with that of historical periods.

The general, universal scheme of variation in the conditions of the Earth's aerial and liquid envelopes during the development of our planet has not been disturbed by the specific climatic features of the individual geological periods, such as the sheet glaciation of the Upper Pre-Cambrian or Upper-Paleozoic (Gondwana region), the hot and humid climate of the Lower and Middle Carboniferous periods, or the arid conditions in the Devonian, Upper Permian, and Lower Triassic periods.

* This is a condensation of a paper read at the Third Astrogeological Conference at the Geographical Society of the Academy of Sciences of the USSR (Leningrad, 9 May 1960).

3. Climatic variations constitute rhythms or cycles of different durations. Short periods of climatic fluctuations have left their distinct imprints on sediments of all the geological ages, both in the continental facies (lacustrine-glacial and proper lacustrine sediments) and in the marine facies, especially in shallow marine and lagoon sediments. These features include rhythms of saliferous and carbonate or argillaceous-carbonate sediments (Figure 1), varved structure of lacustrine and marine oozes containing numerous intercalations found in the skeletal parts of microorganisms or algal residues, etc. Finally, short climatic rhythms are vividly reflected by the structure of organic matter, including annual rings of fossil wood as well as those in the xylem of present-day trees (Figure 2), structural regularities of accumulation layers of carbonate algae (Figure 3), structures of mollusk shells, etc.

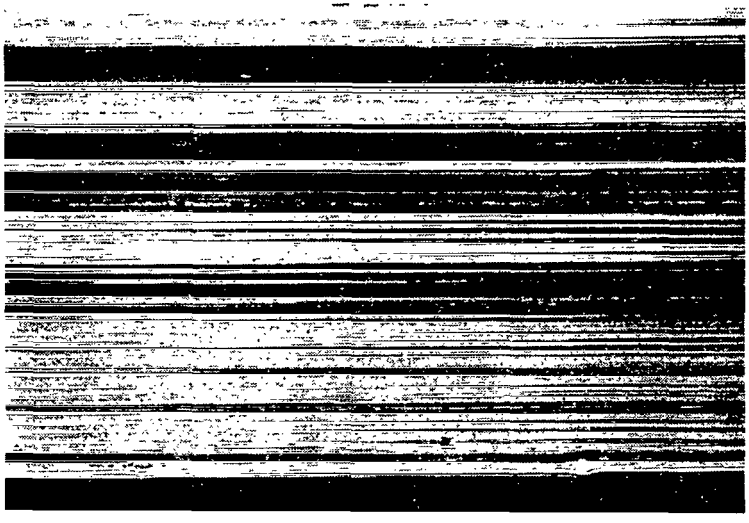


FIGURE 1. Rhythmic banding of an organogenic argillaceous limestone (a polished specimen from a transverse section). Middle Eocene. "Green River" formation, Colorado. Distinct rhythms corresponding to sunspot cycles (after Bradley, 1929).

Short climatic periods correspond to the principal seasons of the year (more rarely to shorter periods, i.e., parts of seasons), as well as to periods of 2 to 3, 5, 11, 20 to 22, 35, and 70 years (Figures 4 and 5). As yet, cycles of 100, 1000, 10,000 to 12,000 years, etc. can be established only with a small degree of certainty. The maximum duration of well-established climatic cycles approaches 180 to 200 million years.

In studies of the banding of sediments and of the climatic rhythms, the reliability of inferences depends on proving the annual nature of the principal banding elements, i.e., of a conjugated pair of elementary layers corresponding to summer and winter, or more precisely to the autumn-winter and the spring-summer seasons. This task is facilitated when the

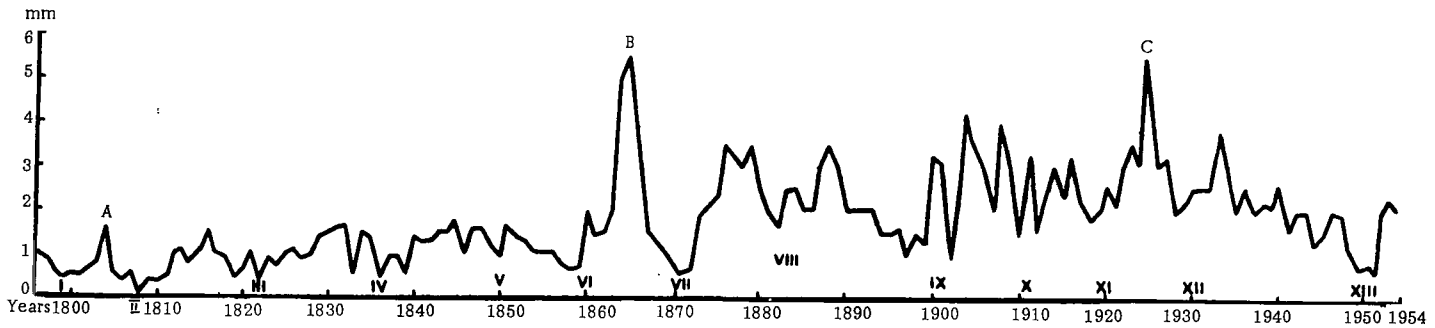


FIGURE 2. Diagram of annual increments of the xylem of a present-day larch (Larix dahurica) for the period from 1796 to 1954. The maximum increments exhibit distinct traces of 3-year climatic cycles, while the minimum increments reflect sunspot cycles (about 12 years). Rhythms of 60 to 65 years are less distinct (A, B, C). The right bank of the Lena River upstream from the town of Yakutsk.

investigator deals with banding in organogenic structures, such as separate bioherms or entire reef structures, and even more so when he deals with fossil wood. Investigation of varved clays (varve sediments) in Sweden, Norway, and Finland and recently also in the USA demonstrated that this problem can be adequately solved for periglacial lacustrine sediments as well (Figure 6). In studies of the banded sediments of marine and continental origins, it is sometimes very difficult to establish the seasonal nature of the banding.

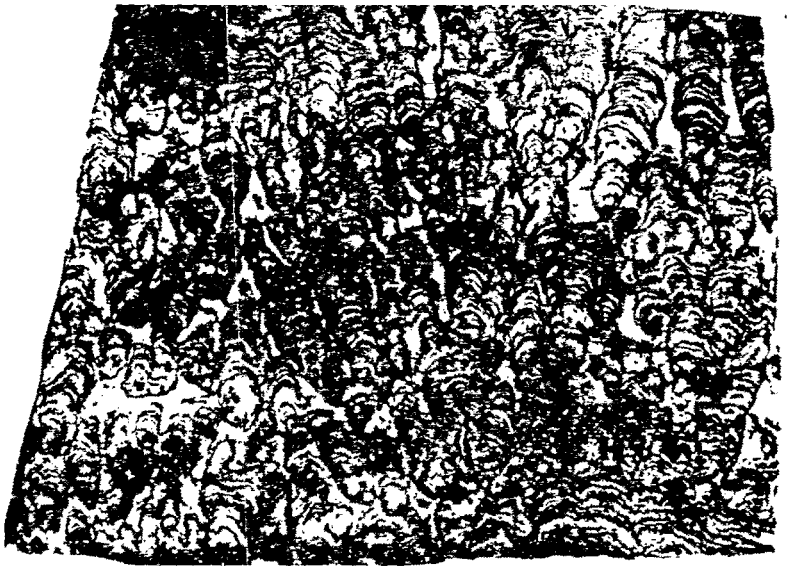


FIGURE 3. Structure of carbonate algae (of Collenia type). Lower Ordovician. Podkamennaya Tunguska River. The sharply delineated dark, more argillaceous varves separate complexes of annual layers corresponding to the 11-year cycle. Rhythms of 3 and 5 years can be detected within these cycles.

As yet, the vast factual data amassed by geologists has been only partially utilized in specialized paleoclimatic analyses. As an example De-Geer's monumental review (1940) with its numerous varve-correlation diagrams may be cited; studies of it may yield very rich material on Upper Glacial climatic variations in Sweden.

4. Apart from the rhythmic banding due to exogenic factors (primarily climatic variations) there also exists a rhythmic banding of endogenic origin which is most clearly manifested by the structure of carbonate or siliceous sediments formed by Recent and Quaternary thermal springs (Figure 7 and 8) as well as during older geological periods. This is vividly illustrated by the banding of jaspers among the volcanogenic Devonian deposits in the South Urals and Altai (Figure 9). Banding of endogenic type has not yet been adequately studied. However, the available data suggest that the rhythms of endogenic banding generally obey the same regularities as do the exogenic rhythms.

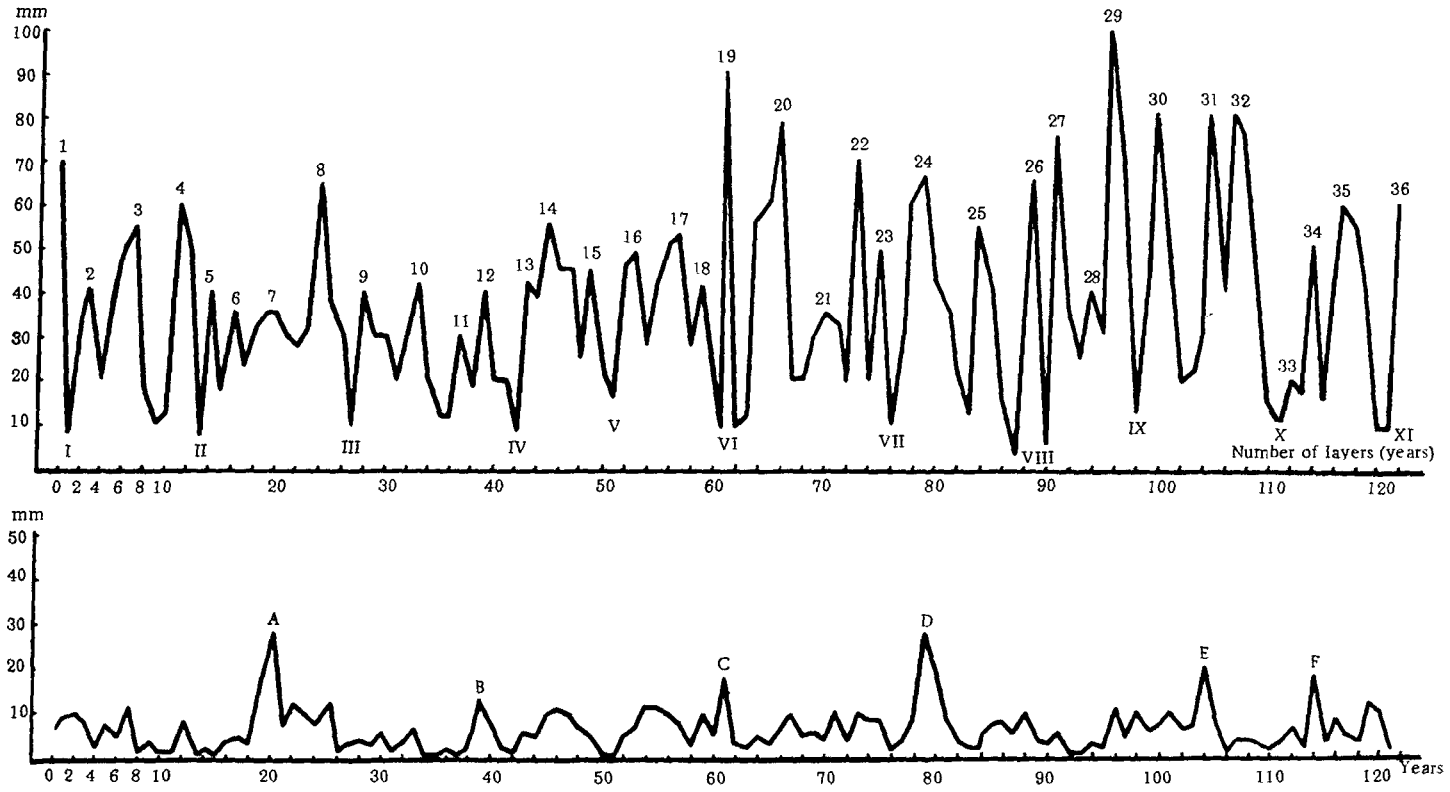


FIGURE 5. Paleoclimatic curves. Upper diagram — according to annual increments of summer sediments (calcareous varves); lower — increments of sediments during the winter season (thin marly varves). Lower Cambrian. Kutorgina suite on the Lena River opposite the village of Botomai: 1—36 — maximum increments of sediments corresponding to 3-year cycles; I—XI — minima corresponding to the 11-year (sunspot) cycles; A—E — maximum increments of winter sediments corresponding to periods of 20 to 25 years.

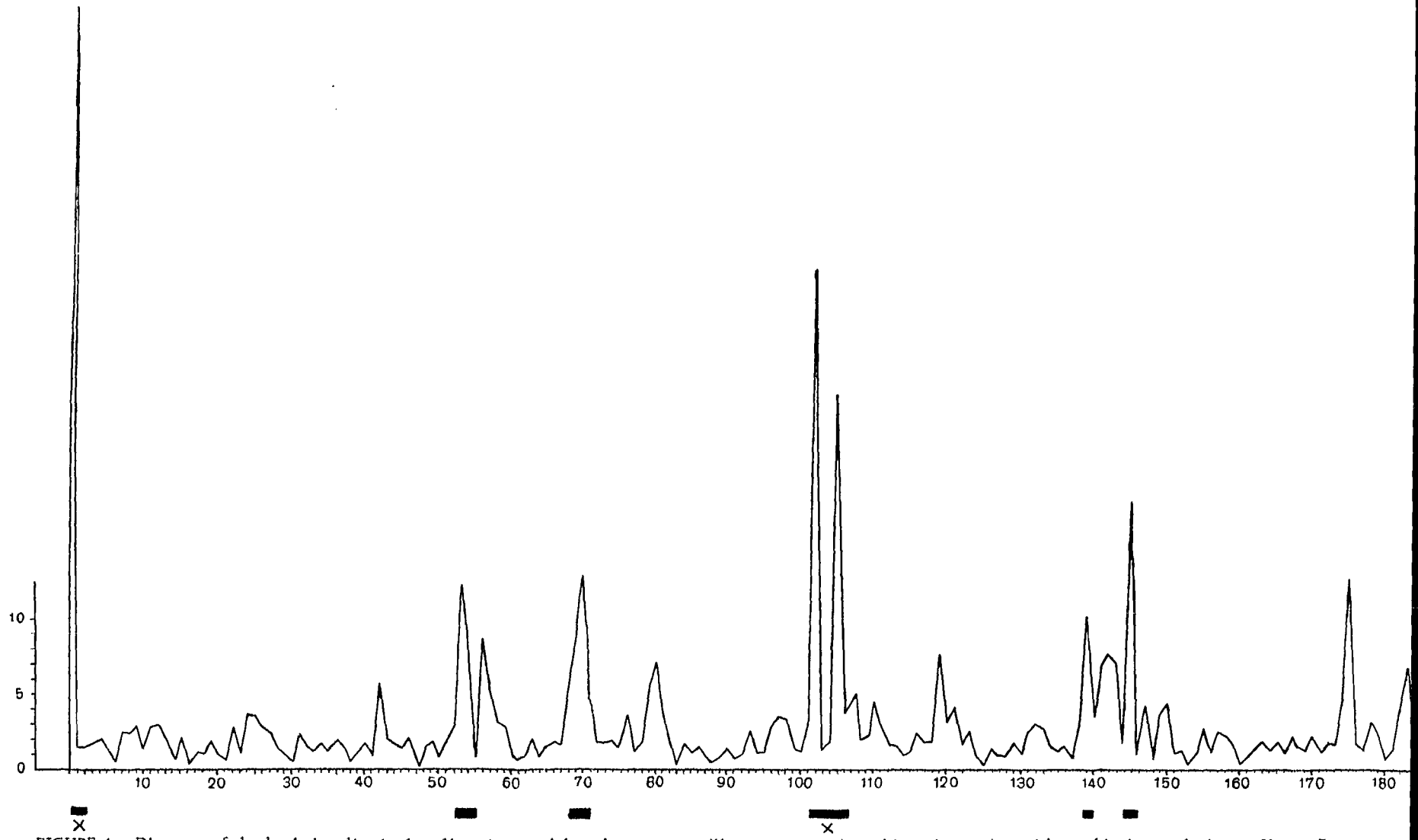
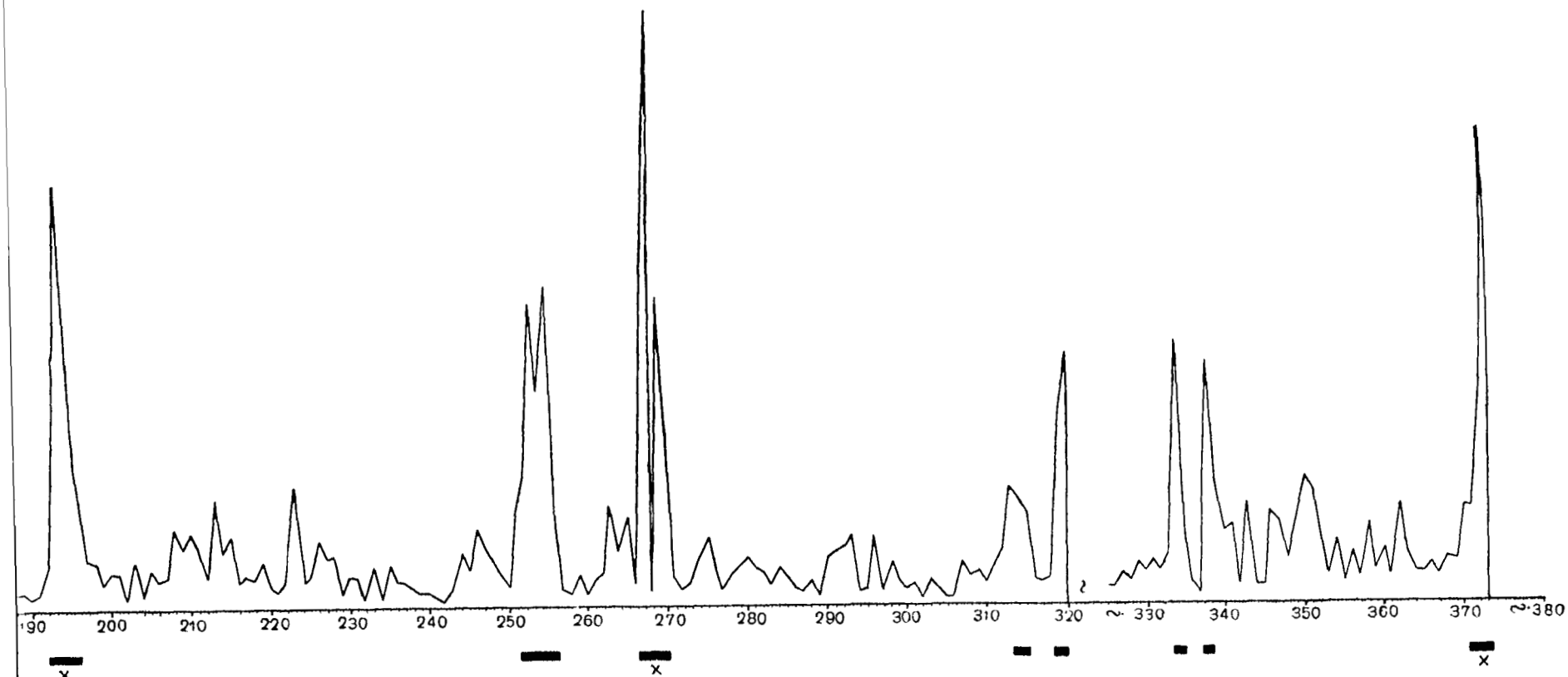


FIGURE 4. Diagram of rhythmic banding (paleoclimatic curve) in micaceous-argillaceous quartzite schists alternating with marble intercalations. Upper Proterozoic scale (a total of approximately 380 years); the vertical axis represents the thickness of annual layers (mm). Many sections of the curve display rhythms of 3, 5, and carbonate composition. The average duration of these rhythms is 50 to 55 years. The very thick carbonate varves possibly result from secular rhythms (80 to 100 ye

Layers (varves) of pure carbonate composition

X Very thick carbonate varves



e Vitim River, at the town of Bodaibo. The horizontal axis in the diagram represents the geochronical
12 years; moreover one can notice rhythms whose boundaries are accentuated by thick varves of

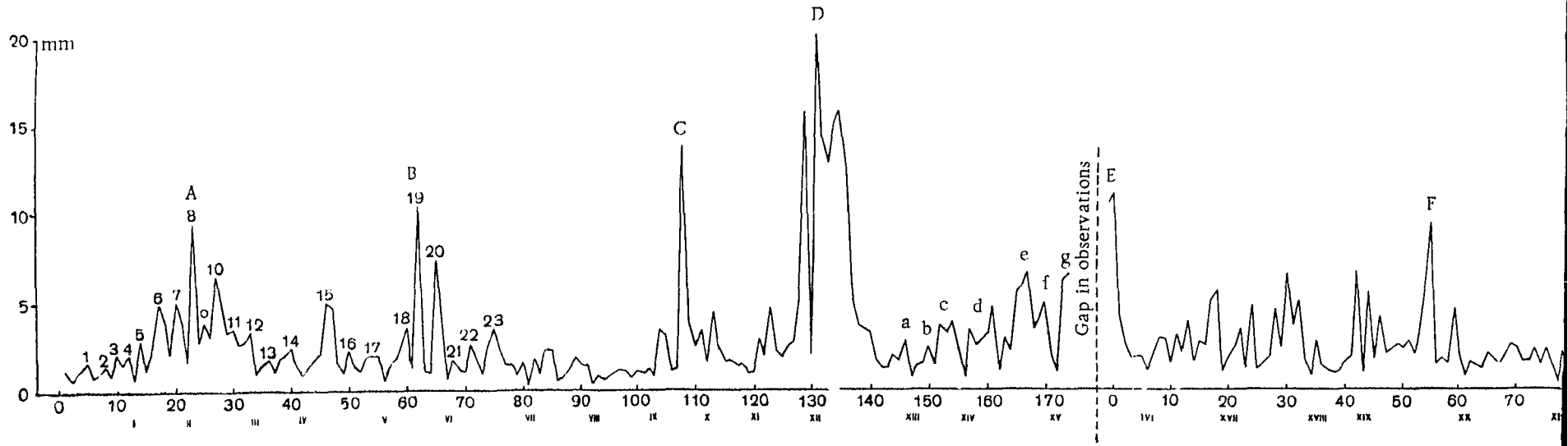
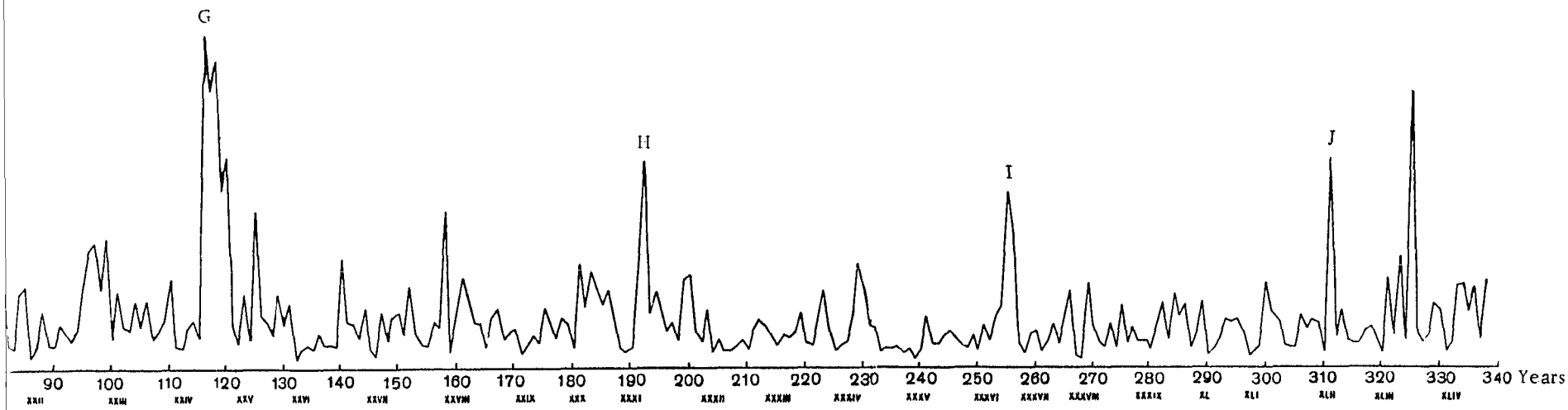


FIGURE 6. Paleoclimatic curve based on annual precipitation increments in Middle Quaternary lacustrine varve clays lying between moraines of stages I and II of the maxi
from the village of Kyzyl-Many. 1—23, etc. — triennial cycles; a-g, etc. — five-year cycles; I—XLIV — sunspot cycles of 1 to 16 years (mean duration, about 12 years);



ım glaciation. Altai Mountains, Chuiskaya Steppe, left bank of the Chagan River 7 km upstream
\—J — climatic cycles of 35 to 60 years.

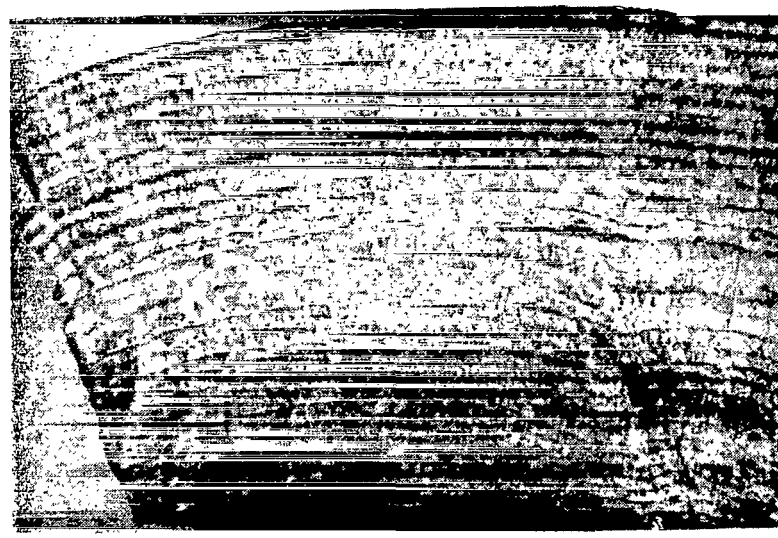


FIGURE 7. Rhythmic banding in travertines deposited by thermal springs. Kazakhstan, Tarbagatai Range, Kel'dy-Murat River. Photograph by Yu. A. Tverdislov.

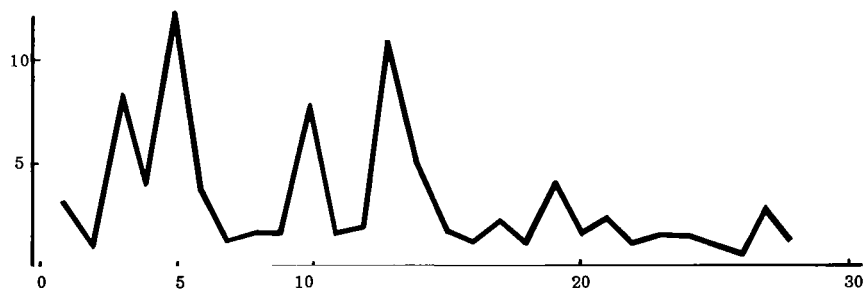


FIGURE 8. Rhythmic banding in aragonite ("onyx marble"). Caucasus, Armenia, Agamzalinskoe deposit. Rhythms of 3, 5 and 8 years.

5. In many cases the climatic periods established by geologists agree remarkably well with periodicities of cosmic phenomena established by astronomers. These include the fairly well-studied periodic variations in the intensity of solar radiation. This probably explains not only the minor rhythms (which include, among others, the period of 11 to 12 years that has been known to many geologists and paleogeographers for a long time), but also climatic cycles of considerably longer duration, such as the major stages in the climatic variations during the glacial periods and corresponding variations in the development of sheet glaciers. Traces of such stages can be perceived in the solar radiation curves for the last 600,000 years constructed by Milankovitsch.

FIGURE 9. Rhythmic banding of endogenic type. Gray jaspers. Devonian. Kolyvan steppe in Rudnyi Altai. Banding rhythms correspond to periods of 3, 12 and 20 years.

6. We are still in complete ignorance of the nature of the largest climatic variations on a scale of hundreds, thousands, and millions of years. One may only speak, with some measure of certainty, of the reflection of the complete galactic revolution of the solar system in the general course of geological processes and climatic evolution of the Earth. This period of revolution, which is 175 to 180 million years according to Parenago, is probably paralleled by the incidence of tremendous terrestrial glaciations which have been termed the "cosmic winters". This subject will be discussed in somewhat greater detail below.

The existence of geological (and probably also climatic, in the broad meaning of this word) cycles of even greater duration, comprising several periods of complete galactic revolutions, i.e., as much as 700 to 1000 million years, may be considered. Special attention should be drawn to the problem of the "Upper Pre-Cambrian" which has recently been considered from a new, though far from unquestionable, slant. The latest absolute geochronological data based mainly on studies of the Pre-Cambrian on USSR territory indicate, fairly consistently, the tremendous duration of time consumed in the accumulation of the so-called "Riphean", or "Sinian"* complex, of about 700 million or even a billion years.

The field geologists, thoroughly acquainted with these strata, have been amazed by their absolute dating, although it can hardly be reconciled with the accepted concepts of the typical physiographic and geological conditions of the Upper Pre-Cambrian. These include the relatively small average thickness of strata and the Eocambrian predominance of very rapidly accumulated continental and shallow marine sediments, such as strata of cross-grained sandstones, reef limestones, conglomerates, tillites, etc.; the absence of regionally consistent lacunes and traces of large diastrophic phases in Eocambrian sections; and finally the insignificant evolution of the organic nature mainly represented by the blue-green algae, whose general habit remained

* The term was a very poor choice in the case of the USSR, but unfortunately it has become widely adopted on account of its introduction into the unified stratigraphic scale used in geological mapping.

TABLE 2. Number of structures of different dimensions

Width, km	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	135	140	150	160	170	175
5	28	2	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
10	1	—	5	1	142	1	1	1	2	—	9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
15	—	—	1	—	16	2	2	—	1	—	2	—	—	1	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—
20	—	—	1	1	4	1	3	1	16	—	—	—	1	2	1	—	—	—	5	—	—	—	—	—	—	—	3	—	—	—
25	—	—	—	—	2	—	1	1	2	1	2	—	1	1	—	—	—	1	3	—	—	—	—	—	—	—	1	—	—	—
30	—	—	—	—	—	—	—	1	8	2	4	3	2	3	1	—	—	—	195	—	3	—	2	2	—	1	3	2	1	1
35	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	1	1	1	—	—	—	1	—	1	—	—	—
40	—	—	—	—	—	—	—	—	—	—	—	—	—	2	1	1	1	—	2	—	1	—	—	—	—	—	1	—	—	—
45	—	—	—	—	—	—	—	—	—	1	—	2	3	—	—	—	—	—	1	—	1	—	—	—	—	—	—	—	—	—
50	—	—	—	—	—	—	—	—	—	1	—	—	3	1	—	—	—	—	9	—	—	—	1	—	—	—	8	—	—	—
55	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	1	—	—	—	—	—	—	—	—
60	—	—	—	—	—	—	—	—	—	—	—	—	1	2	—	—	—	—	2	—	—	—	1	1	—	—	3	2	—	3
70	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3	—	—	—	—	—	—	—	—	—	—	—
75	—	—	—	—	—	—	—	—	—	—	—	—	—	4	—	—	—	—	2	—	—	—	1	—	—	—	3	—	—	2
80	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—
100	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	18	—	—	—	—	—	—	—	4	—	—	5
110	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—
125	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—
130	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
150	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—
170	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
175	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
200	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
225	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
250	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
300	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
325	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
350	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
360	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
400	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
450	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
500	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
600	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
650	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
800	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Total number of structures (Figure 3, curve A)	29	2	7	3	164	4	7	4	29	3	19	3	7	22	4	1	2	1	243	1	6	1	4	4	1	1	31	4	1	11

ngth, km																															Total number of structures (Figure 3, curve B)
80	185	200	225	250	270	275	300	320	325	350	400	425	430	450	500	550	600	605	700	750	800	850	900	945	950	1000	1100	1200	1300	
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	31
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	163
—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	28
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	39
—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	17
—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	235
1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6
—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	10
—	—	3	1	1	1	—	7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	9
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	35
—	—	3	—	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2
1	—	—	—	—	—	—	3	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	20
—	—	2	1	2	—	1	7	—	1	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	9
—	—	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	27
—	—	2	—	3	1	—	57	1	1	3	3	—	—	1	—	1	—	—	—	—	—	—	—	—	1	2	—	—	—	3
—	—	—	—	—	—	—	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	103
—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
—	—	2	—	—	—	1	8	—	—	—	—	1	—	1	1	—	—	—	1	—	—	—	—	1	—	1	1	1	—	5
—	—	—	—	—	—	—	—	—	—	1	3	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	1
—	—	2	—	—	—	—	2	—	—	2	1	—	1	2	—	—	—	—	—	1	—	—	—	—	—	1	1	1	—	4
—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—	3	—	—	—	13
—	—	—	—	—	—	—	1	—	—	—	—	—	—	1	—	1	1	—	—	—	—	1	—	—	—	6	6	2	2	21
—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	1	—	—	—	1	—	—	—	—	—	1	—	—	—	3
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	1	—	—	—	—	—	—	—	—	—	—	—	—	1
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	2	—	1	—	3
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	1
1	19	3	6	6	1	2	91	1	2	8	9	1	1	7	2	3	2	1	2	3	1	1	1	1	1	17	9	5	2	823

essentially unchanged throughout the entire Upper Pre-Cambrian, including not only its uppermost horizons but partly the Lower Cambrian as well.

In this connection it is important to note that minor rhythms of climatic variations, including the secular rhythm, are excellently reflected in the Upper Pre-Cambrian deposits, especially in varved shales which are a facies of periglacial lakes (South Urals, Yenisei Range, Patom Plateau, etc.).

The discrepancies between the geological and the absolute geochronological data are so marked and fundamental that one is completely justified in treating the "Upper Pre-Cambrian enigma" as one of the most acute unsolved problems of modern geology. The difficulties entailed in elaborating the Upper Pre-Cambrian geochronology might necessitate a discussion of the problem of the constant duration of the terrestrial day and the terrestrial year, and their possible variation in the course of geological history, i.e., the existence during terrestrial history of cycles or periods differing in the velocities of the Earth's rotation about its axis and its revolution about the Sun.

There are certain indications that Upper Pre-Cambrian is an instance of a completely separate, independent cycle in the Earth's development, being the longest known cycle.

7. The relationship between the climatic periodicity and that of the geological processes themselves (primarily diastrophism) has hardly been studied. The well-known formula involving a definite relationship between exogenous and endogenous phenomena (for instance, the dependence of large-scale glaciations upon orogenetic stages) needs considerable revision. There are reasons to assume that both groups of phenomena (endogenous and exogenous) are due to the same general extraterrestrial causes, i.e., to factors of a cosmic nature. However, in the subsequent development of events the mutual or, more frequently, unilateral influence of certain phenomena on other phenomena must have gradually manifested itself, and become very strong in certain cases. For instance, the grouping of continents and their configuration, and the uplifting of large continental areas in the form of mountain ranges or plateaus may have facilitated the development of glacial covers, although in themselves they were not the causes of glaciation. These causes must be sought in a general decrease of the mean annual temperature on the Earth's surface due to cosmic factors, probably the same factors as those that must have caused disturbances in the subcrustal portions of the planet and deformations of its solid shell.

8. The existence of prolonged stages or periods in the development of the Earth's structure, of 150 to 200 million years has been suggested (Belousov, 1951). It follows from the above statements that these periods agree closely with the "cosmic" winters," i.e., they correspond to the galactic year. Their nature should apparently be studied from this approach.

A few years ago (Lungersgauzen, 1956, 1957) the important role played in the Earth's history by the orogenic and magmatic cycles comprising periods of 38 to 45 million years was noted. The analysis was performed by superimposing on the geochronological background peaks corresponding to the most important geological events such as orogenic manifestations, intrusive and effusive magmatism, maxima of the transgressions and regressions of the sea, etc. This processing of factual data yielded closely

TABLE 3. Dimensionality of structures with respect to their depth and length

Depth, m	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	135	140	150	160
15	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
25	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—
50	—	—	—	—	1	—	1	2	2	1	9	2	—	1	—	1	1	—	33	—	2	—	1	—	—	—	5	2
100	—	—	—	—	4	—	—	—	—	—	—	—	—	3	—	—	—	—	8	—	—	1	1	—	1	—	2	—
150	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	19	—	—	—	—	—	—	—	—	—
200	—	—	—	—	5	—	1	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1
400	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
500	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4	—	—	—	—	—	—	—	2	—
600	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—
800	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
978	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1000	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	11	—	—	—	—	—	—	—	—	—
1500	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1700	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—
2000	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4	—	—	—	—	—	—	—	1	—
3000	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—
4000	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3	—	—	—	—	—	—	—	—	—
4500	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
5500	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
6000	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4	—	—	—	—	—	—	—	—	—
7000	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Total number of structures (Figure 4, curve C)	—	—	—	—	10	—	2	2	2	1	10	2	—	4	1	1	1	—	91	—	2	1	2	—	1	1	11	3
Maximum depth, m	1	1	1	1	200	1	200	50	50	50	200	50	1	100	1000	50	50	1	6600	1	50	100	100	1	100	25	2000	200
Maximum difference between the height of uplift and the depth of subsidence (according to Tables 3 and 4)	1	1	1	1	1200	1	300	100	350	100	1200	100	1	1100	1100	1	100	1	8000	1	150	1	200	1	1	1	5000	400

Length, km																																		Total number of structures
0	175	180	185	200	225	250	270	275	300	320	325	350	400	425	430	450	500	550	600	605	700	750	800	850	900	945	950	1000	1100	1200	1300		
nber of structures																																	
-	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		1
-	—	—	—	—	—	—	—	—	12	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—		2
-	2	—	—	2	1	—	—	—	12	—	—	1	1	—	—	—	—	1	—	—	—	—	—	—	—	—	—	2	1	—		87
-	—	—	—	4	—	—	1	—	—	—	—	2	1	—	—	1	1	—	1	—	1	—	1	—	—	—	—	1	1	2	—		48
-	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—		2
-	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1		11
-	—	—	—	—	—	—	—	—	1	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		1
-	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		8
-	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—		2
-	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		1
-	—	—	—	1	—	—	—	—	5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—		1
-	—	—	—	—	—	—	—	—	1	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		18
-	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—		1
-	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—		3
-	—	—	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	1	—	—		7
-	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		4
-	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		1
-	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		1
-	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—		4
-	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		1
-	2	—	—	7	1	1	1	—	37	—	—	6	2	1	1	2	1	2	2	1	1	1	1	—	—	—	—	5	4	3	1		231
	50	—	—	1000	50	2000	100	—	5000	—	—	1700	100	200	500	150	100	2000	7000	25	150	600	100	—	—	—	—	3000	3000	978	200		
	310	—	—	2000	550	2200	—	—	9000	—	—	2400	1100	—	—	1150	1400	2500	7000	—	450	900	—	—	—	—	—	8000	8600	3978	2200		

conforming numerical results for the eastern and western parts of the Siberian platform, Altai, the Eastern Balkhash area, certain parts of the Russian platform, the southern Urals, etc.

Geological periods of 38—45 million years are equal to half of the astronomers' "draconitic period" (about 90 million years), i.e., they can be causally related to the oscillations of the solar system with respect to the galactic plane during the revolution of the Sun in its galactic orbit. The self-evident relationship between climatic variations in the past geological epochs and the above diastrophic cycles has not yet been given special consideration in the literature; studies of this relationship constitute one of the most important tasks of paleoclimatology.

9. The data accumulated during recent years and the probable relationship between geological events and the Earth's evolution as a cosmic body call for critical revisions of geochronology and stratigraphy. Questions have been raised concerning the necessity of correcting the positions of the principal boundaries between the geological groups (eras) and even systems (periods). The solution of this problem is facilitated by the fact that the geological eras practically coincide with the galactic year. According to the new approach, boundaries of eras (or galactic years) may be fixed by stages of the most violent (global) perturbations, such as the great glaciations, involving both the Earth's solid shell (Lipalian, Caledonian, Hercynian, and Alpine orogenic cycles) as well as the hydrosphere and the atmosphere. Some of the probable corrections for the general geochronological scale are already essentially obvious. Such corrections include the differentiation of the Lower Paleozoic as an independent era, expansion of the Mesozoic era, and modification of the lower boundary of Anthropogen (this boundary should be drawn under the Upper Pliocence, which is thus excluded from the Neogene period).

The upper portion of late Pre-Cambrian (or the Eocambrian in the former, narrower and more definite sense of this term) should become the basement of the Paleozoic, more precisely of the Lower Paleozoic group. The Upper Paleozoic group most probably commenced with the Middle (?) Ordovician and was terminated by the Middle Carboniferous. The boundaries of the Mesozoic must be expanded by the addition of Upper Carboniferous and Permian on the one side and nearly the entire Cenozoic on the other. Finally, the commencement of the Recent or Anthropogenic epoch should be situated in the Upper Pliocene, whose deposits exhibit, for the first time, traces of cooling of the climate — a precursor of the subsequent great continental glaciation, while the general character of its fauna and flora distinctly approach the Recent forms.

In all probability, the above statements do not exhaust the problem. Further investigations will aid in establishing a direct relationship between the geochronological subdivisions of the second and the third orders and the cosmic processes. Relationships of this kind have already been delineated with respect to periods of 38 to 45 million years, approaching the geological periods in their duration. The smaller subdivisions of the geochronological and stratigraphic scale (such as time units, stages, and zones) must also find direct analogues in the stages of cosmic evolution, provided they are correctly differentiated.

10. Geologists and paleogeographers may be considerable interested in the part played by the cosmic winters in the development of the Earth's climates and in the duration of glaciations. Data referring to the oldest

(pre-Quaternary) glaciations suggest that the glacial epochs lasted millions of years, 10 million (and possibly even more) in certain cases.

The first, earliest signs of the Gondwanian glaciation were found in the Lower Carboniferous of South America, while the peak of glaciation was reached toward the end of the Upper Carboniferous and even the beginning of the Permian. Ordovician glaciation has been clearly traced, beginning with Tremadocian, and its maximum can probably be dated by the Middle Ordovician epoch. Glacial and conglacial Eocambrian deposits are often kilometers thick, (the Keweenawan period in North America, the Ust-Patom suite or the tillite series in the northern part of the Patom Plateau). Glacial strata proper and accompanying strata sometimes alternate with definitely interglacial lacustrine and shallow-water marine formations, with carbonate remains of algae (Australia; Eocambrian strata in the Polar basin, etc.).

Thus, it may be assumed that the Quaternary glaciation, whose overall duration does not exceed 600,000 to 700,000 years (including the interglacial epochs), marked only the beginning of the great terrestrial glaciations, while the present-day (historical) epoch must be regarded as an interglacial epoch.

II

Glaciation traces are known in the deposits of many geological systems. However, it is only occasionally that they can indicate drastic climatic changes involving entire continents and even the entire planet. Local, orographic glaciations whose deposits have been discovered in Devonian, Jurassic, Cretaceous, Paleogene, etc., should probably be excluded. Caution must also be exercised with respect to certain unreliable data which call for most painstaking checks, such as the report on signs of glacial conditions in the Triassic deposits in the northeastern part of the Russian platform.

It was demonstrated earlier by this author (1956, 1957) that in addition to the Quaternary glaciation the great glaciations probably include those of the Upper Paleozoic and Eocambrian, and apparently also the glaciations of Ordovician, Lower Proterozoic, and possibly also Archean. General reviews of ancient glaciations were given by several authors (Coleman, 1926; Schwarzbach, 1950; Lungersgauzen, 1957, and others). Therefore we shall mention below only certain new or little-known facts.

Glaciation of southwestern Africa (Windhoek and Rehoboth) is usually cited as a classic example of the oldest glaciation known on Earth. This opinion is currently acceptable only with reservations. The Archean dating of the Chuos tillite is now open to doubt in connection with the recent revision of the age estimates of the Damara system which includes the tillite strata. There is a possibility that the tillites will prove to be post-Archean, and possibly even Eocambrian (?).

As yet, no authentic traces of Archean glaciation have been found in the USSR. On the other hand, certain recent findings may indicate a significant cooling of climate in the Archean time on the territory of present-day East Siberia. Southeast of the Aldan shield, in the Toko Lake area (eastern terminus of the Stanovoi Range), the geologist Yu. B. Kazmin of the All-Union Aerogeological Trust (VAGT) found rocks of peculiar habit

ngth, km																																
75	180	185	200	220	250	270	275	300	320	325	350	400	425	430	450	500	550	600	605	700	750	800	850	900	945	950	1000	1100	1200	1300	
of structures																																
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	5
1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
1	1	1	5	—	1	—	1	9	—	—	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	—	—	205
6	—	—	2	—	2	—	1	5	—	—	—	1	—	—	—	—	—	—	—	—	1	—	—	—	—	—	1	—	—	—	117
	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	5
1	—	—	—	—	1	—	—	4	—	1	—	1	—	—	1	—	—	—	—	—	—	—	—	—	—	—	2	—	1	—	36
	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
	—	—	—	1	—	—	—	3	1	1	—	—	—	—	1	—	—	—	—	1	1	—	—	—	—	—	—	—	—	—	29
	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
	—	—	—	—	—	—	—	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	6
	—	—	1	1	—	—	—	2	—	—	—	—	—	—	1	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	23
	—	—	1	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4
	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2
	—	—	3	—	—	—	—	1	—	—	—	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	2	—	—	2
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	46
	—	—	—	—	—	—	—	6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	1	1	—	—	—	6
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	3
	—	—	—	—	—	—	—	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—	1
	—	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	1	—	—	—	27
	—	—	—	—	—	—	—	6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	1	1	—	1	3
	—	—	—	—	—	—	—	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	2
	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	11
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	1
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	41
9	1	1	12	2	5	—	2	54	1	2	2	7	—	—	5	1	1	—	—	1	2	—	1	1	1	1	12	5	2	1	592
2	50	50	100	500	200	—	100	3500	300	300	700	1000	—	—	1100	130	500	—	—	300	300	—	2000	400	1600	1200	5000	5600	3000	2000	

TABLE 4. Dimensionality of structures with respect to their height and length

Height, m	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	135	140	150	160	170
																													Numl
25	—	—	—	—	3	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	1
30	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
50	28	2	7	3	59	4	4	2	17	2	2	1	4	6	2	—	1	1	30	1	3	—	2	2	—	—	3	—	—
75	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—
100	6	—	—	—	17	—	1	—	5	—	2	—	—	3	1	—	—	—	52	—	1	—	—	1	—	—	9	—	—
150	—	—	—	—	1	—	—	—	1	—	—	—	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—	—
200	—	—	—	—	10	—	—	—	—	—	—	—	3	—	—	—	—	—	7	—	—	—	—	—	—	—	3	1	—
225	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
240	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
260	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
300	—	—	—	—	—	—	—	—	4	—	—	—	3	—	—	—	—	—	13	—	—	—	—	—	—	—	—	—	—
350	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
390	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
400	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—	—
500	—	—	—	—	11	—	—	—	—	—	—	—	—	5	—	—	—	—	2	—	—	—	—	—	—	—	—	—	—
600	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—	—
700	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—
900	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—
1000	—	—	—	—	11	—	—	—	—	—	4	—	—	1	—	—	—	—	19	—	—	—	—	1	—	—	1	—	—
1100	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1150	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1200	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1300	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1400	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1500	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	20	—	—	—	—	—	—	—	1	—	—
1600	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1800	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2000	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—
3000	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—
3500	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
5000	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
5600	—	—	—	—	41	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Number of structures (Figure 4, curve D)	29	2	7	3	154	4	5	2	27	2	9	1	7	18	3	—	1	1	152	1	4	—	2	4	—	—	20	1	1
Maximum height, m	100	50	50	50	1000	50	100	50	300	50	1000	50	300	1000	100	—	50	50	2000	50	100	—	50	—	—	—	3000	200	25

occurring in the so-called "Ivakskaya" suite which forms part of the Dzhelatula series of the Upper Archean (in the new meaning of the scope of this term). Here, stratified marbles containing clastic materials occur amidst dark-gray marbles and calciphyres (Figure 10). The clastic material consists of graphite-pyroxene gneisses, pyroxene schists, granite gneisses, quartzites, and certain other rocks that are completely unknown among Archean deposits of the adjacent regions of the Aldan shield, i.e., they are of exotic nature.

The size of fragments reaches 10 cm. The largest fragments are well rounded although angular specimens also occur. The occasional small boulders and pebbles impart to the marble the habit of a pudding. The puddings form lenses, but at the same time are confined to a strictly definite stratigraphic horizon in the profile of the Upper Archean. These lenses are a few meters thick and a few hundreds of meters across.

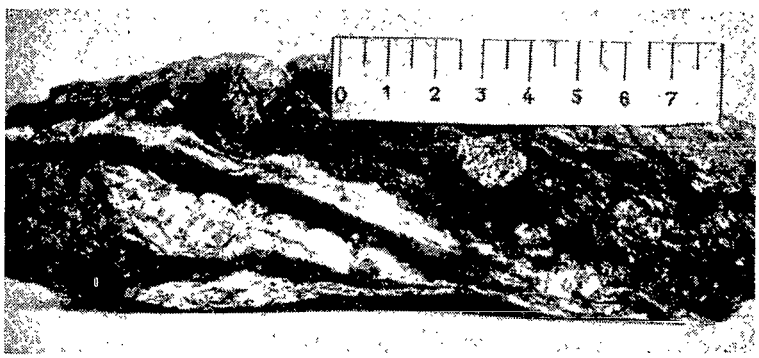


FIGURE 10. Pudding of the type of "marine tillites" — marbles containing small exotic boulders. Archean. Dzhelatula series. Stanovoi Range in the Toko Lake area. Photograph by Yu. B. Kazmin

The great age of these deposits and their Archean dating are unquestionable. The entire rock complex containing the puddings was intensively metamorphosed by an intrusion of alaskite granites, whose absolute age is estimated as 2000 to 2300 million years according to the most recent data. In character these formations resemble the "marine tillites" which have been repeatedly described by A.N. Churakov in the Upper Proterozoic of the Altai-Sayan highlands and which have been known for a long time in South Africa, including the Damar system already mentioned. The mode of occurrence of the puddings amidst carbonate (marine) deposits suggests that they have been formed by the unloading of clastic material embedded in ice floes. The latter were probably formed near the rocky coasts of the continents (or islands) and were carried out into the open sea by the currents.

Proterozoic glacial formations have been somewhat better studied than the Archean ones, yet their stratigraphy is still very little known. The Proterozoic glaciation occurred on the most tremendous scale on the Canadian Shield (Huronian). Probable analogues of the Huronian tillites have been indicated in Ireland, Finland, the southern Urals (puddings of the Barangul Mountain), etc. Possibly they also include the supposedly Proterozoic glacial formations in Africa (the Nabib Desert), Brazil, New South Wales, etc.

Glacial deposits of Late Pre-Cambrian or Eocambrian are well known and have already been described in the specialized literature long ago. The majority of investigators consider the presence of glacial facies to be symptomatic of the Late Pre-Cambrian. However, the correlation of these formations at the present time encounters certain difficulties, whereas it was formerly considered to be fairly simple. As already noted, the volume of Late Pre-Cambrian which was differentiated under the name of the Sinian complex, Riphean group, and Lipalian system has been enormously enlarged by the latest absolute geochronological data, which, however, markedly contradict the general geological data. Nevertheless, a revision of the stratigraphy of glacial formations related to Late Pre-Cambrian is now indicated.

The following are the principal and best known locations manifesting the largest glaciations, beginning with the Late Pre-Cambrian.

Late Pre-Cambrian: North East Land, Spitsbergen, Norway (sparagmites), Scotland (Torridonian), Podolia (Mogilev arkoses), Greenland, North America (tillites of Keweenaw and Great Salt Lake), South Urals, Yenisei Range, Patom Plateau (Figure 11), China (Nangtu tillite, etc.) India, Central Asia, South Africa (Numis tillite, etc.), Australia, New Zealand, etc.

Ordovician: Central Urals, south Germany (?), England (?), Canada, Alaska. Remarkable glacial-marine Tremadocian deposits are known in South America (the Andes), described by Harrington and Keidel.

FIGURE 11. Tillite. Upper Pre-Cambrian. Northern slope of the Patom Plateau, right bank of the Lena River above the mouth of the Patom River. The tillite contains boulders of alaskite granites, marbles, etc.

Upper Paleozoic (Gondwana complex): the well-known glacial deposits of Africa, South America, India, and Australia. The northern hemisphere contains insignificant manifestations of local glaciations, probably of the mountain type, such as on the western slope of the southern Urals.

Quaternary: the tremendous glaciation which comprised vast expanses in Europe, North America, and Asia. The first signs of cooling were observed in the Middle Pliocene. Older, (Paleogenic) glaciations were probably of a purely local character.

My previous works (1956, 1957) provided a brief summary of absolute geochronological data and advanced the conclusion concerning the average duration of the great glaciations, approximately 200 million years, i.e., corresponding to the galactic year. Although certain corrections have been introduced in the geochronological scale in recent years, they do not affect this general conclusion.

It is probably premature to discuss the immediate causes of the great glaciations. It must be acknowledged that the earlier hypothesis concerning the variation in the intensity of solar radiation due to the translocation of the Sun from the region of the galactic nucleus (gravitational maximum) to the peripheral regions of the Galaxy with its minimum stellar density (Lungersgauzen, 1956) is not the only possible one.

One cannot exclude the effect of nebulae, whose galactic distribution is obviously nonrandom. It is well known that the cold dust matter forms tremendous concentrations whose dimensions sometimes reach many parsecs. Possibly, a special significance in this respect attaches to the so-called globules which contain the highest dust densities and consequently possess the lowest translucence. Even if one accepts the average theoretically possible magnitude of light absorption (instead of the maximum one) during the passage of the Sun through the zone of a nebula, the variation in the amount of solar energy reaching the Earth will be sufficient to account for a significant decline of the mean annual temperature on the Earth's surface.

Thus, the predominant concentration of fine dust matter in certain parts of the Galaxy, and the traversing by the solar system of a zone of concentration of cosmic dust over fairly constant sections of the galactic orbit, could satisfactorily explain the periodic nature of the great coolings in the Earth's history and the related intensive development of ice sheets, i.e., the periodicity of cosmic winters.

In conclusion I should like to touch upon another highly specific subject. Without advancing any definite interpretation of the phenomenon, I permit myself to draw the investigators' attention to a circumstance that appears to be significant, namely, the possible asymmetry in the development of the great ice sheets.

The Upper Pliocene and the Quaternary glaciations mostly affected the northern hemisphere. On the other hand, an overwhelming majority of traces of the Gondwana glaciation are concentrated in the southern hemisphere, with the exception of India which, however, also tends toward the southern continental blocks in its general paleogeographic situation (Wegener). The Ordovician glaciation has not yet been adequately studied, but there are grounds to assume that it mainly affected the northern hemisphere. There are at least two glaciation cycles within the extremely

long geological period corresponding to the so-called Algonkian and Eocambrian. Obviously, the Adelaide glaciation (Australia) may serve as a typical representative of the youngest of these glaciations, while Keweenaw (North America) and possibly the Patom Plateau in Siberia (?) are typical of the oldest glaciation.

As yet, very little information is available on the relative stratigraphy of the Middle and especially the Lower Proterozoic and even less on the Archean. Yet, here too there seems to be a definite regularity in the arrangement of glaciation traces beginning with the enormous Huronian glaciation of the Canadian Shield (Lower Proterozoic) and the possibly synchronous boulder puddings of the Barangulskaya suite of the Ural-Tau zone (South Urals) and ending with the supposedly Upper Pre-Cambrian tillites of Damaraland, Windhoek, Rehoboth, and certain adjacent territories in South Africa.

III

The natural sciences are standing on the brink of a new and important stage in their development. This refers not only to physics but also largely to the entire cycle of the geologico-geographical sciences. Some of the most daring and the most disputed ideas and hypotheses advanced by investigators of past generations are finding solid foundations in the data of the most recent investigations. In this respect it is sufficient to point to the fate of Wegener's ideas.

The evolution undergone by the natural sciences in their development is noteworthy and instructive. The age of encyclopedic knowledge and universal concepts was superseded, in the second half of the nineteenth and the beginning of the twentieth century, by a period of the utmost differentiation and separation of the sciences. The new phase that can be currently discerned marks the convergence and cooperation of the most diverse scientific disciplines which, without mutual assistance, cannot provide satisfactory solutions of the most significant and difficult problems which they face.

Never before has such a multitude of unanswered questions arisen in geological science as in recent years, and never before was the possibility of solving these problems, in light of the brilliant successes of physics, astronomy, and especially engineering, so great.

There is no danger of overestimating the importance of the turning point which is occurring before our eyes. The geocentric view of the nature of phenomena that has stubbornly dominated the minds of a majority of natural philosophers (with only a few exceptions; the reader is reminded of Humboldt's "cosmos") has now been destroyed. The main effort has been made, and thought has been liberated from the hypnotic influence of centuries-old traditions. Possibly for the first time since Galilei the Earth has acquired a place of its own in the cosmos, not as a planet but as a complex geological body, and the geological processes have become an inalienable part of the general life of the universe.

REFERENCES

Publications in Russian

BELOUSOV, V.V. Vystuplenie na pervom soveshchanii po voprosam kosmogonii (Speech at the First Symposium on Problems of Cosmogony). — Trudy soveshchaniya. Izdatel'stvo AN SSSR. 1951.

BERG, L.S. O predpolagaemoi svyazi mezhdu velikimi oledeneniyami i goroobrazovaniem (Possible Connection Between the Great Glaciations and Orogeny). — Voprosy Geografii, No.1, Geografgiz. 1946.

BERG, L.S. Klimaty v drevneishie geologicheskie vremena (Climates in the Oldest Geological Times). — Zemlevedenie, Novaya Seriya, 2(12). 1948.

BUBNOV, S. Osnovnye problemy geologii (Fundamental Problems of Geology). — Izdatel'stvo MGU. 1960.

CHURAKOV, A.N. Proterozoiskoe oledenenie i istoriya razvitiya severnoi chasti Eniseiskogo kryazha (Proterozoic Glaciation and History of the Development of the Northern Part of the Yenisei Range). — Trudy VGRO, No.292. 1933.

CHURAKOV, A.N. Proterozoiskoe oledenenie Sibiri (Proterozoic Glaciation in Siberia). — Trudy XVII Sessii Mezhdunarodnogo Geologicheskogo Kongressa, Vol.6. 1940.

LICHKOV, B.L. Dvizhenie materikov i klimaty proshlogo Zemli (Movement of Continents and the Earth's Climates in the Past). — Izdatel'stvo AN SSSR. 1936.

LICHKOV, B.L. O ritme izmenenii poverkhnosti Zemli v khode geologicheskogo vremeni (On the Rhythm of Changes of the Earth's Surface in the Course of Geological Time). — Priroda, No.4. 1941.

LICHKOV, B.L. Geologicheskie periody i razvitie zhivogo veshchestva (Geological Periods and Development of Living Matter). — Zhurnal Obshchei Biologii, Vol.6, No.3. 1945.

LUNGERSGAUZEN, G.F. O fatsial'noi prirode i usloviyakh otlozheniya drevnikh svit Bashkirskogo Urala (On the Facies Nature and Deposition Conditions of the Ancient Suites in the Bashkir Urals). — Sovetskaya Geologiya, No.18. 1947.

LUNGERSGAUZEN, G.F. Periodichnost' v izmenenii klimata proshlykh geologicheskikh epokh i nekotorye problemy geokhronologii (Periodicity in Climatic Variations in Past Geological Epochs, and Some Geochronological Problems). — DAN, Vol.108, No.4. 1956.

LUNGERSGAUZEN, G.F. Periodicheskie izmeneniya klimata i velikie oledeneniya Zemli (nekotorye problemy istoricheskoi paleografii i absolyutnoi geokhronologii) (Periodic Climatic Variations and Great Glaciations of the Earth (Some Problems of Historic Paleogeography and Absolute Geochronology)). — Sovetskaya Geologiya, 59. 1957.

LUNGERSGAUZEN, G.F. Sledy oledenenii v pozdnem dokembrii Yuzhnoi Sibiri i Urala i ikh stratigraficheskoe znachenie (Traces of Glaciations in Late Pre-Cambrian in Southern Siberia and the Urals, and Their Stratigraphic Significance). — Mezhdunarodnyi geologicheskii kongress, XXI sessiya. Doklady sovetskikh geologov. 1960.

MARKOV, K.K. O svyazi mezhdu izmeneniyami solnechnoi aktivnosti i klimatov Zemli (Relationship Between Variations in Solar Activity and the Earth's Climate). — In: Sbornik "Voprosy geografii", No.2, Geografgiz. 1949.
MARKOV, K.K. Paleografiya (Paleogeography). — Geografgiz. 1951.
NALIVKIN, D.V. Uchenie o fatsiyakh. Geograficheskie usloviya obrazovaniya osadkov (Theory of Facies. Geographical Conditions of Sedimentation), Vols. 1, 2. — Izdatel'stvo AN SSSR. 1955.
PARENAGO, P.P. Kurs zvezdnoi astronomii (A Course in Stellar Astronomy). — Gostekhizdat. 1954.
SHOSTAKOVICH, V.B. Sloistye ilovye otlozheniya i nekotorye voprosy geologii (Stratified Silt Sediments and Some Geological Problems). — Izv. VGO, Vol.73, No.3. 1941.
SHOSTAKOVICH, V.B. Ilovye otlozheniya ozer i periodicheskoe kolebanie v prirode (Lacustrine Mud Deposits and Periodic Fluctuations in Nature). — Zapiski Gosudarstvennogo Gidrologicheskogo Instituta, Vol.13. 1934.
ZUBAKOV, V.A. and I.I. KRASNOV. Printsipy stratigraficheskogo raschleneniya chetvertichnoi sistemy i proekt edinoi stratigraficheskoi shkaly dlya nee (Principles of Stratigraphic Differentiation of the Quaternary System, and A Proposed Unified Stratigraphic Scale for It). — Materialy VSEGEI, Novaya Seriya, No.2. 1959.

Publications in Other Languages

ATWOOD, W.W. Eocene Glacial Deposits in Southwestern Colorado. — U.S. Geol. Survey. Prof. Paper 95—B. 1915.
BUBNOFF, S. Grundprobleme der Geologie. — 3 Auflage. Berlin. 1954.
BRADLEY, W.H. The Varves and the Climate of the Green River Epoch. — U.S. Geol. Survey. Prof. Paper 158—E. 1929.
BROOKS, C. Climates Through the Ages; A Study of the Climatic Factors and Their Variations. — McGraw-Hill, New York. 1949. [Russian translation. 1952.]
Du TOIT, A.L. The Geology of South Africa. London. 1939.
GEER, G. de, Geochronologie Suecica Principles. — Kungl. Svens. Vetenskaps Akad. Handingar. Tr. ser., Bd. 18, 6, 1940.
MILANKOVITSCH, M. Astronomische Mittel zur Erforschung der erdgeschichtlichen Klimate. — Handbuch der Geophysik, 9, 3, Berlin. 1938.
SCHWARZBACH, M. Orogenesen und Eiszeiten. Zur Ursache des Klimawechsels in der Erdgeschichte. — Die Naturwissenschaften. Heft 17. 1953.
SCHWARZBACH, M. Eine Neuberechnung von Milankowitsch's Strahlungskurve. — Neues Jb. Geol. Paläontol. Mh.6. 1954.
SCHWARZBACH, M. Das Klima der Vorzeit; eine Einführung in die Paläoklimatologie. — F. Enke, Stuttgart. 1950. [Russian translation. 1958.]
SHAPLEY, H. Climatic Change: Evidence, Causes, and Effects. Harvard Univ. Press, Cambridge. 1953. [Russian translation. 1958.]
WEGENER, A. Die Entstehung der Kontinente und Ozeane. — 2 Aufl. Braunschweig. 1936.
ZEUNER, F.E. Dating the Past. An Introduction to Geochronology. — London. 1952.

V. V. Piotrovskii

APPLICATION OF MORPHOMETRY TO STUDIES OF THE EARTH'S RELIEF AND STRUCTURE

The relief of the lithosphere, similar to its inner structure, reflects the most important events in the development of our planet.

Studies of this natural chronicle have contributed considerably to our knowledge of the history of the Earth's development. Yet, even now many unsolved problems remain, one of which concerns tectonic movements and the relief forms conditioned by them. This problem has been discussed by many authors and numerous hypotheses have been advanced; nevertheless no satisfactory solution has thus far been found. Our work represents another attempt to find possible approaches to the solution of this important problem. This paper presents the preliminary results of our work and describes some of the patterns discovered.

The object of our study will be the relief of the lithosphere. The term "relief" is used to cover the entirety of all surface forms of the lithosphere*, including convex and concave surfaces and plains of various geological structures and origins, forming complex combinations with one another and bearing complex relationships to their environment (Piotrovskii, 1959, 1961).

Our definition of relief leads us to regard the lithosphere, as well as its relief, as a complex but at the same time integral natural formation, whose development obeys general laws and which is connected by complex interrelationships with its environment, i.e., the Earth's external and internal shells. Furthermore, the lithosphere and its relief may to a considerable extent be regarded as the "products" of the interaction of processes taking place in the external and internal shells. The lithosphere and its relief reflect the results of the interaction of energy arriving from interplanetary space (for instance, from the Sun) with the energy enclosed in the bowels of the Earth.

At the same time the entire Earth, being a cosmic body, is closely related in its development to interplanetary space and obeys certain general laws of the evolution of matter which have not yet been completely deciphered.

The effect of terrestrial and cosmic factors which are reflected in the lithosphere and in its relief manifests itself in various ways; furthermore, it varies in time and space. It may also vary in scale and may be composed of quantities of dissimilar orders of magnitude. Obviously, the weaker the effect of any given factor, the weaker also is the process brought about by this factor; the briefer the effect of the given process, the smaller its effect

* In this case we identify the lithosphere with the concept of the "Earth's crust".

on the development of the Earth including its relief; the more limited its spatial distribution, the smaller the area on which the "traces" of its manifestation may appear. On the other hand "minor processes" or "forces" may cause large-scale changes in the structure of the Earth and the Earth's crust, and in its relief, when they act together over long periods of time to produce a combined effect.

The genesis of relief forms is discussed in detail in specialized works; at this point we shall concentrate our attention on the dimensionality of these forms.

The Earth's relief is a complex combination of a variety of forms whose dimensions vary widely. The largest form is represented by the Earth itself while the smallest investigated forms may be represented by the very small-scale forms of sand ripples produced on sandy surfaces by wind, small waves, or weak currents.

The dimensionality of the relief forms — their length, width, vertical development (height and depth), steepness of their slopes, etc. — is studied in a special branch of geomorphology (science of the Earth's relief) which is known as morphometry. Until recently this branch was underdeveloped, although certain isolated attempts in this field were made some time ago. Currently morphometry has been receiving increasing attention, and the accumulated morphometric data already reveal, in certain cases, some patterns which facilitate the grouping of relief forms into certain categories; even an attempt to elucidate certain general causes of the development of the leading forms has been made.

Our work on the collection and generalization of morphometric data was begun several years ago. A work of this kind encounters great difficulties. The morphometric relief data available in literature are scattered through innumerable papers; moreover, these data are usually quite inaccurate (because averaged numerical data are reported) and incomplete. Many papers and special works provide information only on the length and width of the relief forms, but not on their height nor depth; other papers only describe the width and height without referring to length; still others only mention the steepness of slopes, without providing any other dimensions, and so on. In spite of the difficulties encountered, our preliminary processing of the collected data enabled us, in 1959, to discern patterns in the ratios of the basal area (length and width) and the vertical development (height and depth) for a considerable number of relief forms including the tectonic structural forms, i.e., forms deriving from movements of the Earth's crust.

In classifying relief forms and tectonic structures according to their morphometric indexes, we found a regular repetition of the ratios of these indexes, while the forms themselves could be grouped in a general morphometric series consisting of 18 orders (Table 1). In these orders the ratios of length, width, and vertical development are constant (1 : 3 and 1 : 10), and they comprise the most common relief forms and tectonic structures of the Earth.

Obviously some of the forms differ in their dimensions from those indicated in the orders of the general morphometric series. However, further processing of the data made it possible to establish the limits of deviation and to find out that wide forms (rounded in plan) deviate by 20—30% from the linear indexes of the series, whereas their areas largely

TABLE 1. Morphometric series of relief forms and tectonic structures

Order of forms and structures	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII
	Dimensions (m and m^2)								Dimensions (km and km^2)									
Length	0.1	0.3	1	3	10	30	100	300	1	3	10	30	100	300	1000	3000	10 000	30 000
Width	0.03	0.1	0.3	1	3	10	30	100	0.3	1	3	10	30	100	300	1000	3000	10 000
Area	0.003	0.03	0.3	3	30	300	3000	30 000	0.3	3	30	300	3000	30 000	300 000	3 000 000	30 000 000	300 000 000
Height or depth	0.003	0.01	0.03	0.1	0.3	1	3	10	0.03	0.1	0.3	1	3	10	30	100	300	1000
	0.01	0.03	0.1	0.3	1	3	10	30	0.1	0.3	1	3	10	30	100	300	1000	3000

Notes: 1. Deviations in length and width may reach ± 10—20%. In the case of height (or depth), larger negative deviations observed. In large orders, level areas (forms) correspond to plains.

2. The maximum absolute elevation of relief forms is about 9000 m, the maximum relief amplitude is 20,000 m, and the maximum amplitude of the surface of the tectonic basement is about 30,000 m. In orders IX to XV the numerical data for height and depth may characterize not only the relief amplitude but also the depth of the roots of tectonic structures (especially the bottom row of numbers). In orders XVI to XVIII the numerical data on height and depth mainly characterize the depth of the roots.

conform to those of the series. In very long forms, the ratio of width to length reached 1 : 10 in isolated cases, but their areas were similar to those of the forms of the respective order in the general series.

The first order of the general morphometric series comprise the smallest relief forms of the type of sand ripples and the smallest folds occurring in plastic clays, shales, etc. The last orders of the series include entire highlands, continents, and oceanic depressions (Gerassimov's "geotectures", 1946). Order XVIII comprises forms which are commensurable with the Earth itself, their areas approaching those of the hemispheres.

The general morphometric series is simple and consistent (see Table 1), the transition from one order to another being completely uniform over the entire series and with respect to all the indexes (length, width, height, and area). The uniformity is expressed by the same ratios as in every individual order (1 : 3 and 1 : 10) but with a certain difference. The difference consists in the ratio of 1 : 3 alternating with the ratio of 1 : 3.3 for every other order (10, 30, 100, 300, etc.). The index for areas increases regularly by a factor of 10 in transition from one order to the next.*

The general morphometric series proved to withstand various transformations to other ratios (1×2, 2×3, 3×5, etc.); the attempts to eliminate the existing ratio of 1 : 3.3 also failed. In such attempts the actual relief forms are satisfactorily arranged in two or three adjacent orders but after that the theoretically calculated values disagree with the factual data. The regularity involved in the transition from forms of a certain order to the next order (i.e., their trebling) is especially evident in relief forms which definitely derive from wave action (sand ripples, barchan ridges, etc.). When enlarged threefold, these forms undergo the most successful transition to geometrically similar bodies of the next order with the least rearrangement of their original elements. The elements are preserved when the slopes of the small ridges are taken over by the larger ridges, as shown in Figure 1, while the material is transported over short distances (from negative relief forms to crests of the nearest ridges).

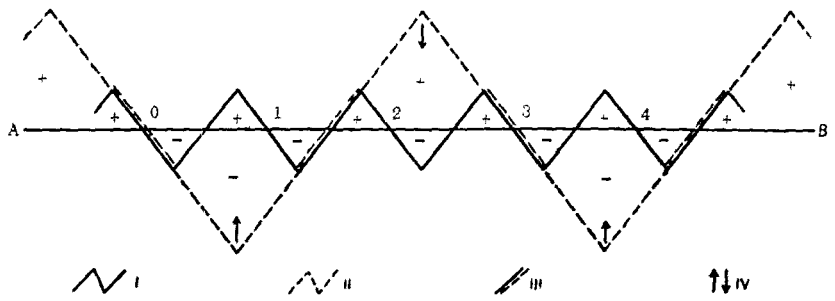


FIGURE 1. Scheme for the summation of "waves" of two adjacent orders:

0, 1, 2, 3, 4 — nodes of the "waves"; I. small "waves"; II. large "waves"; III. common surfaces; IV. direction of movement.

* A.Cailleux and J. Tricard arrived at conclusions similar to ours in their work "Problems of the Classification of Geomorphological Phenomena" (see collection "Problems of the Climatic and Structural Geomorphology [Voprosy klimaticheskoi i strukturnoi geomorfologii]. 1959).

Figure 1 presents a scheme of sand ripples formed from local material on a horizontal surface, preserving the general basic level. The scheme must be somewhat modified for large relief forms developed on the Earth's spherical surface and for forms whose genesis involves influx of additional material (or loss of material), yet the general principle and the derived ratios are preserved.

It will be seen from Figure 1 that if two adjacent forms — a positive and a negative one (i.e., crest and trough) — are taken as the basic ones (as single "wave"), then the next order is obtained by combining three such "waves". Moreover, the scheme shows that the "momentum" stored between the large positive forms (in the "trough") is capable of producing a smaller ridge. In the crest portion of the large ridge there is a "momentum" tending to flatten it and subdivide it into two smaller crests. Both cases are observed in nature when the spacing of ridges are changed, and when individual large forms become excessively wide. Thus, the transition of forms from one order to another is effected with relative simplicity, while their similarity is partially maintained by the common element of slopes and by certain permanent properties of rocks (shear angles, angles of repose, etc.).

The discussion of the subject of the general morphometric series at a meeting of the geomorphological commission of the Moscow branch of the Geographical Society of the Academy of Sciences of the USSR and at the scientific conference of the Moscow Institute of Engineers for Geodesy, Aerial Photography, and Cartography (MIIGAiK) in the spring of 1960 resulted in a decision on the necessity for further studies of the patterns discovered. However, further work was very much hindered by the above-mentioned nonuniformity of the morphometric data available in the literature. We obtained comparatively uniform data only after publication of the "Neotectonic Map of the USSR" (Karta noveishei tektoniki SSSR) compiled by a large group of authors, with N.I. Nikolaev and S.S. Shul'ts as general editors (1959). In contrast to other specialized maps (geological, tectonic, etc.), this map reflects the dynamics of the Earth's crust; it clearly exhibits the tectonic structural forms which underwent subsidence or uplift over a relatively brief (geologically speaking) time period.

Notwithstanding the large inaccuracies in the map, due to the lack of knowledge of certain territories, excessive generalization of the structures, the crude scale of the sections scale, and other causes we succeeded in measuring 823 tectonic structural forms with sufficient accuracy for a first approximation. The preliminary data elicited from an analysis of this material will be presented below. The results of measurements performed on this map are listed in Tables 2—6, and the reader can analyze the material presented by any available method.

It is seen from Table 2 that structures of certain orders dominate among those marked on the map. Structures of the smallest areas are about 10 km long and 5 km wide (28 structures).

Structures of the next order are about 30 km long and 10 km wide (143 structures). Then come structures 300 km long and 100 km wide (57 structures), followed by those having a length of 900 to 1300 km and a width of 100 to 300 km.

It may be assumed that the highest order is formed by tectonic structures over 1300 km long but relatively narrow (complex geosynclinal belts), and

TABLE 5. Dimensionality of structures with respect to their depth and width

Depth, m	Width, km: 5	10	15	20	25	30	35	40	45	50	55	60	70	75	90	100	110	125	130	150	170	175	200	225	250	300	325	350	360	400	450	500	600	650	800	Total number of structures
	Number of structures																																			
15	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
25	—	—	—	—	—	1	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2
50	—	11	3	3	3	33	2	1	1	8	—	1	1	4	1	7	—	—	—	5	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—	87
100	—	1	—	—	—	18	1	—	—	—	1	—	—	4	—	9	—	—	—	1	—	—	4	1	—	3	—	—	1	—	—	—	1	—	—	48
150	—	—	—	—	—	5	—	—	—	—	—	—	2	—	—	10	—	—	—	—	—	—	2	—	1	—	—	—	—	—	—	1	—	—	—	21
200	—	5	—	—	—	2	—	—	—	—	—	1	—	—	—	—	—	—	—	1	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	11
400	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	1
500	—	—	—	—	—	4	—	—	—	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	8
600	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	2
800	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	1
978	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	1
1000	—	—	—	1	—	11	—	—	—	—	—	—	—	—	1	5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	18
1500	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
1700	—	—	—	—	—	2	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3
2000	—	—	—	—	—	4	—	—	—	—	—	—	—	1	—	2	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	8
3000	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—	4	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	7
4000	—	—	—	—	—	3	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4
4500	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	1
5500	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
6000	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4
7000	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	1
Total number of structures	—	20	3	5	3	86	3	1	1	8	1	2	5	10	2	45	—	2	—	8	—	—	7	1	1	11	—	—	1	1	—	1	2	1	—	231
Maximum depth, m		200	50	1000	50	4000	100	50	50	50	100	200	1700	2000	1000	6000		500		200			800	100	150	7000			100	400		150	100	600		
Maximum difference between the height of uplift and the depth of subsidence (according to Tables 5 and 6)		1200	250	3000	150	5500	300	1050	1050	3050	150	2300	3200	5000	1300	9000	100	1400	100	3700	—	1000	6400	—	2150	12000	—	—	—	700	—	1450	1000	—	—	

by structures whose width and length exceed 1000—1500 km (platforms); there exist only a few of these, and they were not included in our tables. Thus, the map marks structures corresponding to orders XI—XVI of the general morphometric series.

The tectonic structures form nodes, as it were, in which the structures are concentrated in considerable numbers and are extensively developed in the vertical direction (uplift or subsidence, see Tables 3—6). Structures of intermediate dimensions are less widespread and are generally less developed vertically. In certain places the intermediate structures form secondary "nodes", such as structures about 150 km long. At these nodes the morphometric indexes of the structures are multiples of the principal indexes in the morphometric series. A noteworthy feature is an abrupt increase in the number of structures wherever even a single one of their morphometric indexes (length or width) approaches 10, 30, 100, or 300 km.

The neotectonic map shows that the characteristic structures of platform regions possess plan shapes approaching circles and broad ellipses, while the characteristic structures of the geosynclinal belts are elongated, in the shape of ellipses and spindles, as has already been noted by several authors. These features of platforms and geosynclinal structures make it possible to differentiate corresponding "fields" in Figure 2, where the structures are grouped according to their width and length, i.e., regions which characterize the platforms and the geosynclinal structures.

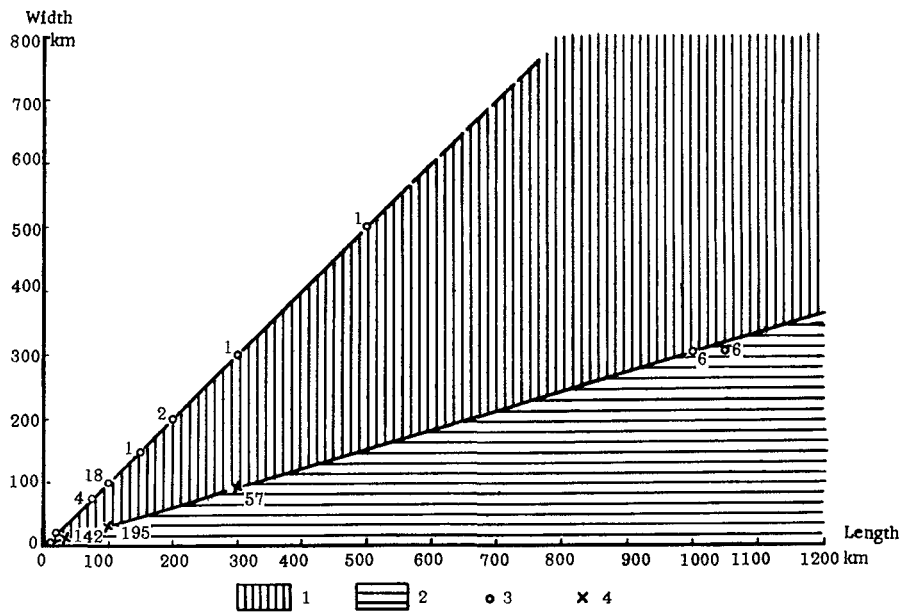


FIGURE 2. Dimensionality of structures with respect to length and width. The graph illustrates Table 2, and is marked only with the nodal groups of structures represented in the table:

1. field of the platform structures; 2. field of the geosynclinal structures; 3. 1 to 30 structures; 4. over 30 structures.

In order to provide a vivid idea of the relative arrangement of structures characterized by different indexes, graphs were plotted in the simple ratios taken from the principal tables. These graphs clearly exhibit parts of curves corresponding to the most widespread structures (Figures 3 and 4).

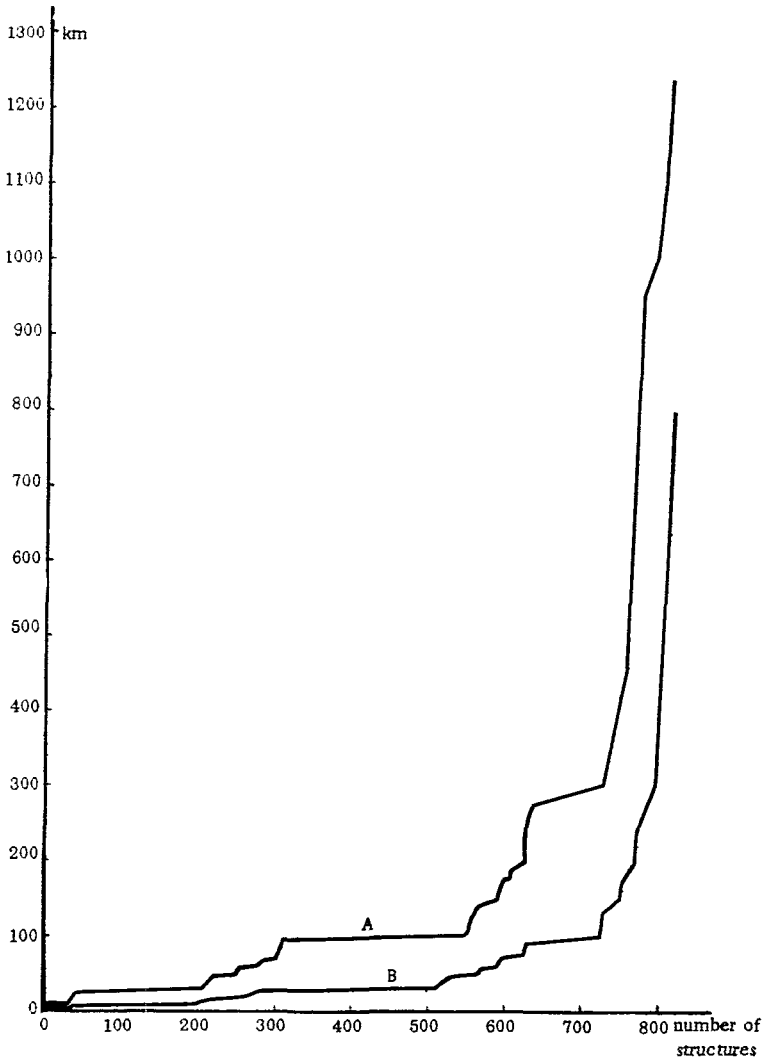


FIGURE 3. Dimensionality of structures with respect to length (curve A) and width (curve B). The graphs illustrate Table 3.

An analysis of the vertical development of tectonic structures represented on the neotectonic map by the height of uplifts and depth of subsidences occurring over a comparatively brief geological time reveals a significant vertical underdevelopment of the positive structures compared with the

height of uplifts of the same length and width according to the morphometric series (Table 1). This phenomenon can largely be explained by the vigorous denudation of the uplifts. Furthermore, the map features heights referring only to brief periods of geological time (Neogene and Quaternary), whereas the structures were undergoing uplifting over a considerably longer period of time. The uplifting of many structures had started earlier, in the Mesozoic and even in the Paleozoic.

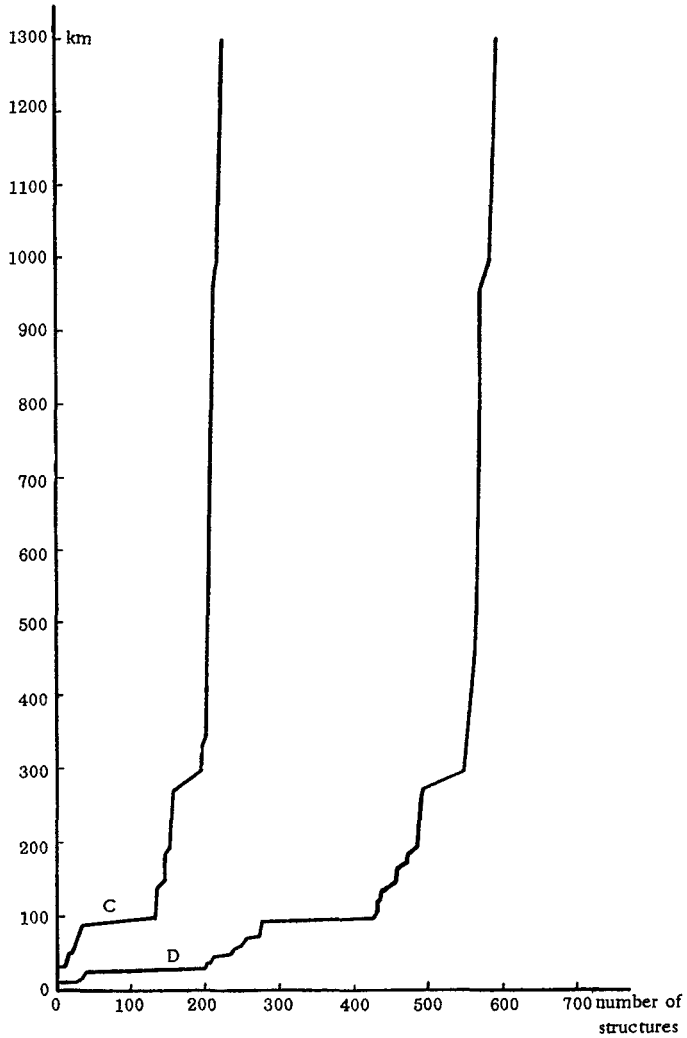


FIGURE 4. Dimensionality of negative (curve C) and positive (curve D) structures with respect to length. The graphs illustrate Tables 3 and 4.

The vertical development of the negative (subsiding) structures is fuller than that of the positive (uplifting) structures. This may be explained

by their being preserved by sedimentary strata and possibly also by the additional load provided by the accumulating sediments.

In negative structures of high orders (XIII – XV) the depth of subsidence marked on the neotectonic map is less than that calculated theoretically. This may be attributed to the fact that the depth of subsidence of the structures does not refer to the surface of the basement but rather to a certain stratigraphic horizon. The true "bottom" of the trough is located at a considerably greater depth, as can be readily seen in the instance of the Fergana depression. This explanation is substantiated by material found in the literature, tectonic maps, etc. Moreover, one must take into account the fact that many structures are still in a formative stage and have not yet reached their full development.

A marked feature is the absence from the map of small negative structures. This is probably explained by their masking by sediments (so that the structures were not discovered by the investigators), as well as by the fact that many negative relief forms are occupied by lakes of which only a small number were marked on the map.

Studies of the morphometric features of the structures marked on the neotectonic map of the USSR revealed considerable inaccuracies in some parts of the map. This is illustrated by the structures in northeastern Siberia, which are depicted in an overgeneralized manner, so that their contours are quite distorted from the viewpoint of the possible mechanism of their formation. Another instance is provided by the representation of the positive (uplifted) structures in Transbaikalia which are shown excessively long on the map, whereas actually they are lenticular. These errors stand out very clearly in a comparison of the positive structures of this region with the negative structures which are depicted more correctly on the map. Moreover, the authors of the map overgeneralized the structures of Altai, Sayan, and several other regions, whereas the Tien Shan structures are depicted in a much more satisfactory manner.

Morphometric processing of the data given on the neotectonic map of the USSR achieved several purposes.

First, the basic material confirmed the patterns that were delineated in establishing the general morphometric series.

Secondly, it became possible to identify the tectonic structures of the platform and the geosynclinal regions, their graphic expression, and their morphometric features (see Figure 2).

Finally, consideration of the characteristics of well-studied structures and the patterns expressed in the form of the morphometric series made it possible to reveal the errors and inaccuracies in the map itself. This confirmed the importance of taking account of the morphometric indexes in the compilation of specialized geological, tectonic, and similar maps.

Analysis of varied and voluminous morphometric data, including those taken from the neotectonic map of the USSR, shows that the general morphometric series of relief forms and tectonic structural forms expresses numerically the general pattern that can be traced in nature and that is reflected by small and large relief forms and by tectonic structures of exogenous and endogenous origins.*

* In 1960–1962 a similar regularity in the lunar relief was discovered by Shemyakin (1962).

In this paper we shall not discuss the development of the relief forms due to external agents (wind, running water, etc.), although this aspect is important for the elucidation of all the general patterns; we shall, however, dwell on certain interesting interrelationships which became manifest during attempts to correlate the tectonic structures with the internal structure of the Earth's crust.

Obviously, any relief form or tectonic structure possesses "roots", i.e., a zone in the Earth's crust which is under the load of a positive relief form or whose deformation was involved in the formation of the form itself. Examples are seen in the interaction of engineering structures with their bed, manifesting itself in the subsidence of the ground under loads or in the decompression of structures in foundation pits. These subjects are studied in detail by geological engineers, builders, and other specialists and are beyond the scope of this paper. In the case of small structures and small relief forms the zone of their interaction with the underlying masses is usually small, but large relief forms may also possess deeper "roots".

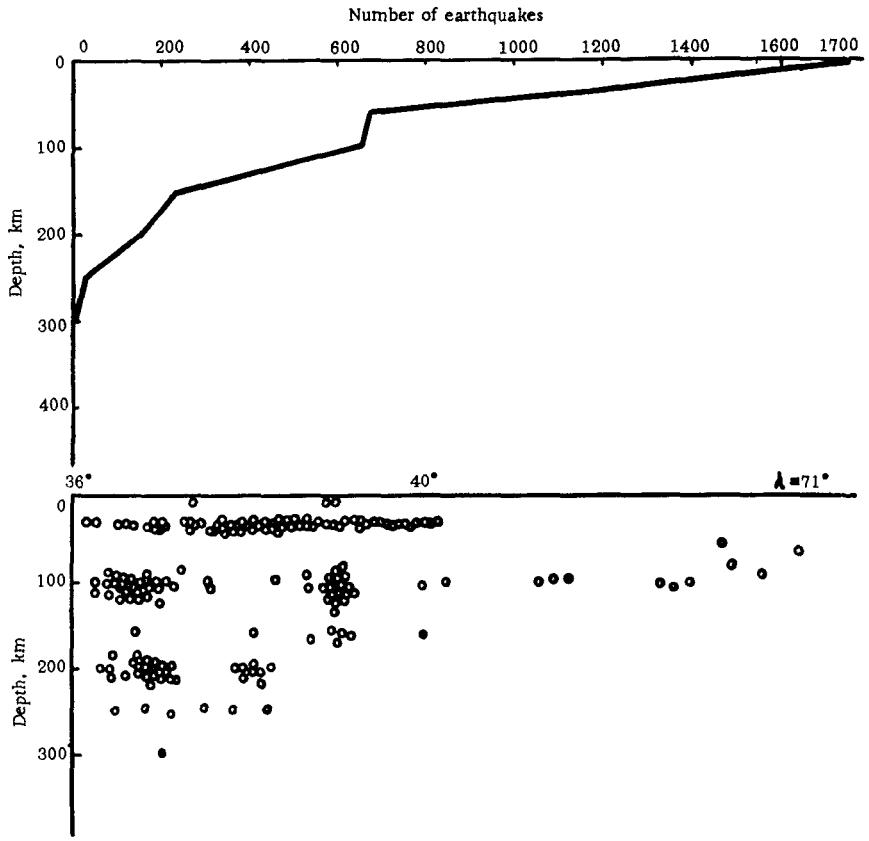


FIGURE 5. Location of earthquake hypocenters in the mountainous regions of Central Asia, according to Rozova (1950) and Magnitskii (1953). The graph illustrates Table 7.

by their being preserved by sedimentary strata and possibly also by the additional load provided by the accumulating sediments.

In negative structures of high orders (XIII—XV) the depth of subsidence marked on the neotectonic map is less than that calculated theoretically. This may be attributed to the fact that the depth of subsidence of the structures does not refer to the surface of the basement but rather to a certain stratigraphic horizon. The true "bottom" of the trough is located at a considerably greater depth, as can be readily seen in the instance of the Fergana depression. This explanation is substantiated by material found in the literature, tectonic maps, etc. Moreover, one must take into account the fact that many structures are still in a formative stage and have not yet reached their full development.

A marked feature is the absence from the map of small negative structures. This is probably explained by their masking by sediments (so that the structures were not discovered by the investigators), as well as by the fact that many negative relief forms are occupied by lakes of which only a small number were marked on the map.

Studies of the morphometric features of the structures marked on the neotectonic map of the USSR revealed considerable inaccuracies in some parts of the map. This is illustrated by the structures in northeastern Siberia, which are depicted in an overgeneralized manner, so that their contours are quite distorted from the viewpoint of the possible mechanism of their formation. Another instance is provided by the representation of the positive (uplifted) structures in Transbaikalia which are shown excessively long on the map, whereas actually they are lenticular. These errors stand out very clearly in a comparison of the positive structures of this region with the negative structures which are depicted more correctly on the map. Moreover, the authors of the map overgeneralized the structures of Altai, Sayan, and several other regions, whereas the Tien Shan structures are depicted in a much more satisfactory manner.

Morphometric processing of the data given on the neotectonic map of the USSR achieved several purposes.

First, the basic material confirmed the patterns that were delineated in establishing the general morphometric series.

Secondly, it became possible to identify the tectonic structures of the platform and the geosynclinal regions, their graphic expression, and their morphometric features (see Figure 2).

Finally, consideration of the characteristics of well-studied structures and the patterns expressed in the form of the morphometric series made it possible to reveal the errors and inaccuracies in the map itself. This confirmed the importance of taking account of the morphometric indexes in the compilation of specialized geological, tectonic, and similar maps.

Analysis of varied and voluminous morphometric data, including those taken from the neotectonic map of the USSR, shows that the general morphometric series of relief forms and tectonic structural forms expresses numerically the general pattern that can be traced in nature and that is reflected by small and large relief forms and by tectonic structures of exogenous and endogenous origins.*

* In 1960—1962 a similar regularity in the lunar relief was discovered by Shemyakin (1962).

In this paper we shall not discuss the development of the relief forms due to external agents (wind, running water, etc.), although this aspect is important for the elucidation of all the general patterns; we shall, however, dwell on certain interesting interrelationships which became manifest during attempts to correlate the tectonic structures with the internal structure of the Earth's crust.

Obviously, any relief form or tectonic structure possesses "roots", i.e., a zone in the Earth's crust which is under the load of a positive relief form or whose deformation was involved in the formation of the form itself. Examples are seen in the interaction of engineering structures with their bed, manifesting itself in the subsidence of the ground under loads or in the decompression of structures in foundation pits. These subjects are studied in detail by geological engineers, builders, and other specialists and are beyond the scope of this paper. In the case of small structures and small relief forms the zone of their interaction with the underlying masses is usually small, but large relief forms may also possess deeper "roots".

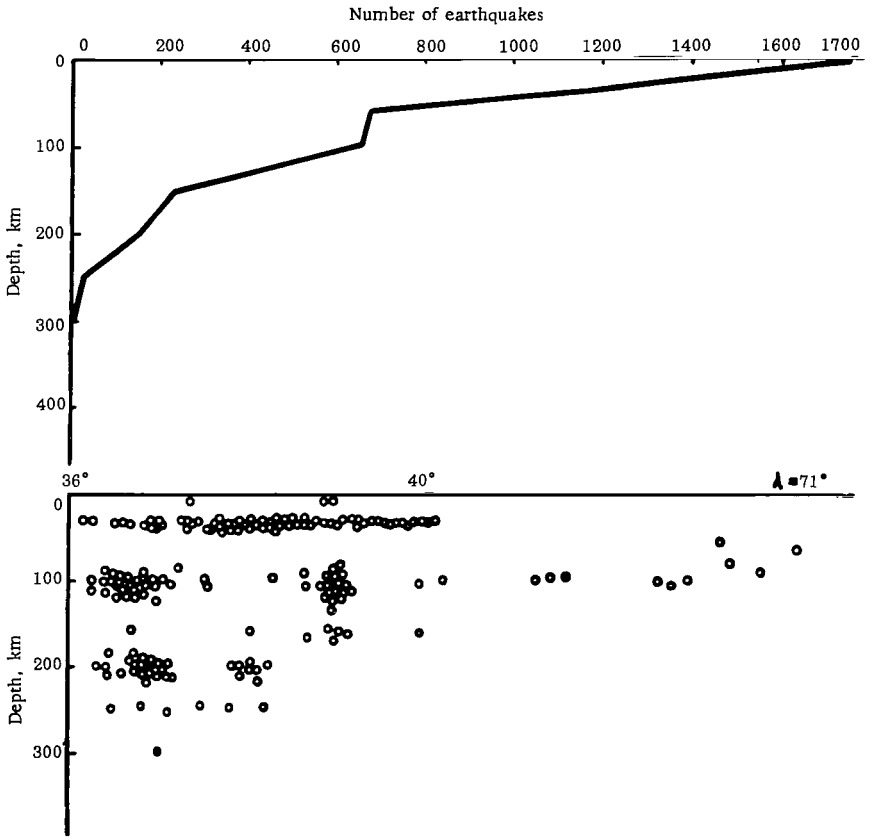


FIGURE 5. Location of earthquake hypocenters in the mountainous regions of Central Asia, according to Rozova (1950) and Magnitskii (1953). The graph illustrates Table 7.

TABLE 6. Dimensionality of structures with respect to their height and width

Height, m	Width, km: 5	10	15	20	25	30	35	40	45	50	55	60	70	75	80	100	110	125	130	150	170	175	200	225	250	300	325	350	360	400	450	500	600	650	800	Total number of structures
	Number of structures																																			
25	—	3	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	5
30	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
50	26	63	12	22	8	36	2	3	2	10	1	—	—	6	—	7	—	—	—	1	—	—	2	—	1	—	—	—	—	—	—	—	—	—	205
75	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
100	5	34	—	8	6	32	—	4	—	5	—	—	1	4	—	6	1	—	1	2	—	1	1	—	—	1	—	—	—	—	—	—	—	—	—	117
150	—	—	1	—	—	2	—	—	—	—	—	—	1	—	—	1	—	—	—	—	—	1	1	—	—	1	—	1	—	1	—	—	—	—	—	5
200	—	—	10	—	—	8	1	—	—	4	—	—	1	3	—	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	36
225	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
240	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
260	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
300	—	—	—	—	—	8	—	—	2	1	—	—	—	—	1	12	—	1	—	1	—	—	—	—	—	1	—	—	1	1	—	—	—	—	—	29
350	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	1
390	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
400	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	2	—	1	—	—	—	1	—	—	1	—	—	—	—	—	—	—	—	—	—	6
500	—	11	—	—	—	4	—	—	3	1	—	—	—	—	—	2	—	—	—	1	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	23
600	—	—	—	—	—	2	—	—	—	—	—	—	—	1	—	—	—	—	—	2	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4
700	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2
900	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	2
1000	—	12	—	—	—	21	—	1	1	2	—	3	—	1	—	2	—	—	—	1	—	1	—	—	—	1	—	—	—	—	—	—	—	—	—	46
1100	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	1
1150	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6
1200	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3
1300	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	1
1400	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
1500	—	—	—	—	—	20	—	—	—	—	—	—	—	—	—	4	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	1	27
1600	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3
1800	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	2
2000	—	—	—	1	—	—	—	—	—	—	—	1	—	—	—	4	—	—	—	1	—	—	—	—	1	3	—	—	—	—	—	—	—	—	—	11
3000	—	—	—	—	—	—	—	—	—	1	—	—	—	2	—	2	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6
3500	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
5000	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	1
5600	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	1
	—	20	1	2	—	11	—	1	—	1	—	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	41
Total number of structures	36	143	25	34	14	149	3	9	8	27	1	18	4	17	1	8	1	3	1	11	1	4	6	—	4	11	1	1	—	2	1	1	1	—	1	592
Maximum height	100	1000	200	2000	100	1500	200	1000	1000	3000	50	2000	1500	3000	300	3000	100	900	100	3500	1	1000	5600	1	2000	3000	500	200	1	300	300	1300	900	1	1500	

Morphometric analysis of tectonic structures and relief forms revealed that these fall regularly into several orders; consequently their "roots" must also be arranged in certain stages in the Earth's crust and not in a random fashion. In order to test this conclusion we analyzed data on the location of earthquake hypocenters provided by several sources, including Rozova (1950) and Magnitskii (1953). Graphs based on these data (Table 7) display an remarkable similarity to our own graphs (see Figures 3, 4, and 5), suggesting a fairly pronounced relationship between tectonic structures and the internal structure of the Earth's crust.

TABLE 7. Number of earthquakes and the depth of their hypocenters in the mountainous regions of Central Asia

(according to Rozova, 1950, and Magnitskii, 1953)

Depth of hypocenters, km	Number of earthquakes
0—10	521
35 ± 10	545
60 ± 10	29
100 ± 20	410
150 ± 20	95
200 ± 20	123
250 ± 20	28
300 ± 20	4

On the basis of the patterns discerned from the general morphometric series (see Table 1), it may be assumed that most earthquakes occurring in Central Asia are related to the development of structures of the order XIII, XIV, and XV. These include the Issyk-Kul and the Fergana depressions which correspond to structures of the order XIV. Some of the earthquakes having their hypocenters at depths of 200—300 km are probably related to the development of large planetary structures of the order XVI. A large number of earthquake hypocenters located at depths of 30 and 100 km may correspond to structures of the order XV, which must be about 1000 km long and up to 300 km wide, according to the morphometric series.

The bibliographic sources (Belousov, 1948 , 1954; Azhgirei, 1959) as well as geological, tectonic, and even physical maps depict these structures as geosynclinal. Among the depressions they include sediment-free forms of the type of deep-sea trenches (Kurile Trench, Marianas Trench, and others), the Black Sea depression, and several other seas, while among mountain structures they include the Greater Caucasus, the Alps, the Carpathians, and many others. The intermontane Tarim depression also probably belongs among analogous structures (according to Fedorovich (1961)) its length is 1100—1410 km, its width 420 km (along the meridian of Keriya), with Meso-Cenozoic strata over 14 km thick; the depth of its basement is still unknown). This depression is in the stage of being filled and bears a special relationship to the surrounding relief, i.e., it is fringed by mountain structures. The significance of these structures in the development of the Earth's crust attracts special attention, and analysis of their morphometric characteristics appears to us to be of extreme interest.

At the present stage it may be noted that the long axis of rectilinear structures of the type of the Greater Caucasus drawn at the depth of 30 km under the center of the mountain structure may be regarded as a chord subtending an arc described with a radius of about 6000 km, which is fairly close to the Earth's radius. Since these structures are to a certain extent related to the Earth's dimensions and figure, the other indexes of the entire morphometric series may obey a similar relationship.

In order to examine this possibility, we performed an elementary calculation with the formula

$$l = \frac{r}{\pi},$$

where l is the full wavelength, equal to twice the index of the width of the relief form in the morphometric series (in the case of a combination of a positive with a negative form), r is the Earth's radius (the equatorial radius of 6378 km was used), $\pi = 3.14$ is the factor necessary for the scaling of linear magnitude to a circle (a sphere).

The results calculated are listed in Table 8. They display an interesting agreement with indexes of the morphometric series.

TABLE 8. Correlation of the morphometric series indexes with the wave parameters calculated with respect to the Earth's radius

Order of waves	Wavelength l, km	$\frac{l}{2}$, km	Width of the forms in the morphometric series s, km	Difference $\frac{l}{2} - s$	Order in the series
1	2031.21	1015.6	1000	15.6	XVI
2	646.88	323.44	300	23.44	XV
3	206.01	103.0	100	3.0	XIV
4	65.6	32.8	30	2.8	XIII
5	20.9	10.4	10	0.4	XII
6	6.65	3.32	3	0.32	XI
7	2.111	1.05	1	0.05	X
8	0.6723	0.336	0.3	0.036	IX
9	0,214	0.107	0.1	0.007	VIII
10	0,0681	0.034	0.03	0.004	VII
11	0.0217	0.0108	0.01	0.0008	VI
12	0.0069	0.0034	0.003	0.0004	V
13	0.0022	0.0011	0.001	0.0001	IV
14	0.0007	0.0003	0.0003	0	III
15	0.00022	0.00011	0.0001	0.00001	II
16	0.00007	0.00003	0.00003	0	I

There is no doubt that this calculation calls for further check and study. Possibly it only indicates the direction in which the solution of the problems of interest to us must be sought.

The patterns discovered suggest that the tectonic structural forms formed in the Earth's crust and reflected on its surface in the relief forms derive from certain general processes occurring in the Earth's body, and that they are proportional to the Earth's dimensions and are dependent upon its physical properties.* Most probably such processes are periodic deformations — oscillations or "waves" generated in the Earth's body by various agents, including solar and lunar attraction, variations in the

* Interesting ideas concerning the relationship between relief and the physical properties of rocks will be found in "Inorganic Life of the Earth" (Neorganicheskaya zhizn' Zemli), Part 1, by O. Lukashevich (published in 1908).

Earth's rotation about its axis, variations in the atmospheric pressure, etc. The presence of oscillations of various orders in the Earth has already been established by precise instrumental measurements, but their relief-forming significance still calls for painstaking studies. Quite probably, these oscillations or "waves" are one of the important agents stimulating, regulating, and directing the development of tectonic structures in the Earth's crust. In studies of this problem special attention should be paid to the possible summation of these oscillations and resonance phenomena.

Further studies of the morphometric problems call for additional collection and processing of vast and diversified data, including an enormous amount which are morphometric. These data must be of a higher quality than those heretofore obtained from the literature and from small-scale maps.

Very valuable data are provided by large-scale structural maps compiled by instrumental surveys. Likewise, interesting information can be obtained from studies of fairly accurate maps of the bottom relief of the World Ocean, since the tectonic structures at the bottom of the sea have been less modified by external agents than they have been on dry land. Extremely valuable should be the results of field observations carried out according to a special program.

Methods for collecting morphometric data, their processing and their analysis have not yet been adequately elaborated, but it is already possible to make some tentative recommendations.

In collecting any morphometric data one must avoid all kinds of averaged indexes, since arbitrarily chosen averaging obliterates the possible natural "peaks". Moreover, averaged data collected by one investigator in a certain region are difficult to compare with those from other regions collected by other investigators. The numerical characteristics (length, width, height of uplifting, depth of subsidence, etc.) of the relief structures and forms must be given on a very detailed scale for every relief form and every tectonic structural form, and they must be measured with the maximum accuracy possible in this kind of work.

Working with the neotectonic map, we used an interval of 5 km for plan measurements, corresponding to 1 mm on the map.

In the tables presented in this paper this interval was sometimes changed where structures of the corresponding dimensions were absent from the territory under consideration (the USSR territory). For instance, we did not discover any structures with length of 505, 510, 515, 545 km, nor structures with a width of 155, 165 km, nor several others. The intervals were not shortened in the plotting of graphs (see Figures 2, 3, and 4).

In determining morphometric indexes it is important to establish the level with respect to which the measurements are to be performed. These levels may differ for relief forms of different origins; they must be determined for every specific case, and must be precisely indicated in records, tables, and graphs. In processing vast numbers of homogeneous data, the base level can be established statistically with a sufficient degree of accuracy as the mean of a large number of measurements, even when some of the latter involve errors.

In the course of measurements an index card should be made out for every measured form, and this card should include all the morphometric characteristics recorded in a definite sequence. Such cards make it possible to process the collected data by means of modern computers.

The work done thus far (a brief summary of which has been provided in this paper) leads to the following conclusions:

1. Systematic collection and analysis of morphometric data is an important method of studying relief forms and the tectonic structures of the Earth.

2. The general morphometric series which we established as a result of the preliminary processing of a tremendous amount of data still requires further checking, since our data were incomplete and of insufficient accuracy. However, this series must now be accepted as the numerical expression of natural regularities.

3. At the present time the morphometric series can be employed in the construction and analysis of geological, tectonic, geomorphological, and other specialized maps, in drawing the contours of tectonic structures, in collecting and processing morphometric data, and for other scientific and practical purposes.

4. The pattern expressed by the morphometric series delineates a new approach to studies of the problem of the development of tectonic structures and relief forms.

5. Final checking of the patterns observed calls for further collection and processing of sufficiently accurate morphometric data on a mass scale and according to a uniform program; this will require joint efforts of geologists, geophysicists, and geomorphologists.

REFERENCES

AZHGIREI, G.D. Strukturnaya geologiya (Structural Geology). — Izdatel'stvo MGU. 1959.

BELOUSOV, V.V. Osnovnye voprosy geotektoniki (Main Problems of Geotectonics). — Gosgeolizdat. 1961.

BELOUSOV, V.V. Strukturnaya geologiya (Structural Geology). — Izdatel'stvo MGU. 1961.

BOCH, S.G. and I.I. KRASNOV. Klassifikatsiya ob"ektov geomorfologicheskogo kartografirovaniya i soderzhanie geomorfologicheskikh kart (Classification of Objects for Geomorphological Mapping, and Contents of Geomorphological Maps). — Sovetskaya Geologiya, No.2. 1958.

BORISEVICH, D.V. Universal'naya legenda dlya geomorfologicheskikh kart (Universal Legend for Geomorphological Maps). — Zemlevedenie, Novaya Seriya, Vol.3(43). 1950.

FEDOROVICH, B.A. Proiskhozhdenie rel'efa pustyni Takla-Makan i voprosy ee osvoeniya (Origin of Relief in the Takla-Makan Desert and Problems of Its Economic Development). — In: Sbornik "Kun' Lun' i Tarim", Izdatel'stvo AN SSSR. 1961.

GERASIMOV, I.P. Opyt geomorfologicheskoi interpretatsii obshchei skhemy geomorfologicheskogo stroeniya SSSR (An Essay on Geomorphological Interpretation of the General Scheme of the Geomorphological Structure of the USSR). — Problemy Fizicheskoi Geografii, Vol.12. 1946.

MAGNITSKII, V.A. Osnovy fiziki Zemli (Elements of Terrestrial Physics). — Geodezizdat. 1953.

MARKOV, K.K. Osnovnye problemy geomorfologii (Basic Problems of Geomorphology). — Moskva, Geografgiz. 1948.
MESHCHERYAKOV, Yu.A. Ob otrazhenii v rel'efe Russkoi ravniny antiklinal'nykh struktur tipa valov i kupolov (Reflection in the Relief of the Russian Plain of Anticlinal Structures of the Type of Ramparts and Domes). — DAN, Novaya Seriya, Vol. 79, No. 2. 1951.
MESHCHERYAKOV, Yu.A. Osnovnye elementy morfostruktury Zemli i problemy ikh proiskhozhdeniya (Principal Elements of the Morphological Structure of the Earth and Problems of Their Origin). — Izvestiya AN SSSR, Seriya Geograficheskaya, No. 4. 1957.
NIKOLAEV, N.I. Noveishaya tektonika SSSR (Neotectonics of the USSR). — Trudy Komissii po Izucheniyu Chetvertichnogo Perioda, Vol. 8, Izdatel'stvo AN SSSR. 1949.
NIKOLAEVA, N.I. and S.S. SHUL'TS, editors. Karta noveishei tektoniki (Neotectonic Map). — Gosgeoltekhizdat. 1959.
PIOTROVSKII, V.V. K voprosu o sozdanii obshchei klassifikatsii form rel'efa litosfery (On the Elaboration of a General Classification of the Relief Forms of the Lithosphere). — Trudy MIIGAiK, No. 18, Geoizdat. 1959.
PIOTROVSKII, V.V. K voprosu o migratsii radioaktivnykh elementov i ee znachenii v razvitii litosfery (On Migration of Radioactive Elements and Its Significance in the Development of the Lithosphere).— Ibid., No. 44. 1961.
PIOTROVSKII, V.V. Geomorfologiya s osnovami geologii (Geomorphology and Elements of Geology). — Geodezizdat. 1961.
POLDERVAART, A.H., editor. The Earth's Crust, a Symposium. — Geological Soc. of America, New York. 1955.
Problems of Climatic and Structural Geomorphology. Collection of Papers. [Russian translation. 1959.]
RAMENSKII, L.G. Vvedenie v kompleksnoe pochvenno-geobotanicheskoe issledovanie zemel' (Introduction to Comprehensive Soil-Geobotanical Investigation of Lands). — Ogiz, Sel'khozgiz. 1938.
ROZOVA, E.A. Raspolozhenie epitsentrov i gipotsentrov zemlyatryasenii Srednei Azii (Location of Earthquake Epicenters and Hypocenters in Central Asia). — Trudy Geofian, No. 10. 1950.
SHEMYAKIN, M.M. Zamechatel'nye tsepochki lunnykh kraterov (Remarkable Chains of Lunar Craters). — Priroda, No. 2. 1962.
VOLKOV, N.I. Printsipy i metody kartometrii (Principles and Methods of Cartometry). — Geodezizdat. 1950.
Voprosy vnutrennego stroeniya i razvitiya Zemli (Problems of the Earth's Inner Structure and Development). — Trudy Geofizicheskogo instituta AN SSSR. Moskva. 1955.

G. G. Khizanashvili

FORMATION OF SUBMARINE VALLEYS IN THE LIGHT OF THE DYNAMICS OF THE EARTH'S AXIS

The problem of the formation of submarine valleys has not yet been fully solved. Hypotheses of the subaerial formation of submarine canyons assume improbably large variations in the amount of water in the oceans or similarly large vertical movements of the continent*. Therefore scientists were forced to discard the hypothesis of the subaerial formation of these canyons and to seek an explanation of this phenomenon in underwater processes.

Variations in the ocean level (and consequently the possibility of suitable conditions for subaerial formation of submarine valleys) may also occur without any variation in the amount of water in the oceanic depressions. The hypothesis advanced by Khizanashvili /10/ demonstrates that variations in the ocean level, even of considerable amplitude, may occur on Earth irrespective of any variation in the quantity of oceanic waters. This hypothesis may be briefly summarized as follows: shifts of masses continuously occurring on our planet deflect the rotation axis within the Earth's body; the solid part of the Earth changes its position with respect to its rotation axis; the hydrosphere, being liquid, continued to rotate in such a manner that the minor axis of the oceanic spheroid always coincides with the rotation axis. As a result, the ocean level rises in two opposite quadrants of the Earth's surface while falling in the other two; a rise in level in certain areas is compensated by subsidence in other areas, while the volume of oceanic waters remains unchanged /10, pp. 5—14/.

An explanation of the genesis of submarine valleys based on Khizanashvili's hypothesis suggests that a deflection of the rotation axis within the Earth's body causes a depression in the ocean level in regions approached by the poles. The rivers and other streams follow the retreating seacoast by cutting their valleys through the newly dry land. Subsequently, when the deflection of the rotation axis changes its direction and the poles start retreating from these areas, the ocean level again rises and part of the river valleys become submerged, forming submarine canyons.

Nevertheless, fluctuations in ocean level may still prove inadequate to explain the origin of submarine valleys by erosion. The submarine canyons are not formed unless the retreat of the ocean is followed by vigorous erosion processes which destroy the newly exposed dry land. Consequently, another no less important factor is represented by erosion agents on dry land. One such agent is atmospheric precipitation.

* The variations in the level of the ocean necessary to produce subaerial conditions on areas now under water are attributed by scientists either to a change in the volume of oceanic waters or to a change in the volumetric capacity of the oceanic depressions.

It will be useful to remind the reader of Shepard's view of the lower incidence of submarine canyons in desert regions where the amounts of atmospheric precipitation are insufficient for intensive erosion. Shepard wrote that there are grounds for assuming that canyons should occur less frequently in the zone centered at 30° lat. where the atmospheric precipitation is light. However, this phenomenon may be partially explained by the insufficient number of soundings in this latitude. Yet, characteristically, not a single large canyon has been discovered in the desert region /12, p. 243/. Similarly, the absence of submarine canyons off the Australian shores is related by Shepard to the underdeveloped river system of this continent /9/.

Thus, the following are the two principal prerequisites for the formation of submarine valleys: 1) fluctuations of the ocean level; and 2) adequate atmospheric precipitation to form streams capable of vigorous erosion.

The formation of submarine canyons must undoubtedly be affected by many other factors besides those mentioned. For instance a significant factor may be the relief of the adjacent sea-bottom areas; this factor may assume decisive importance in certain cases. However, the ocean floor is variable everywhere, and while hindering the formation of submarine canyons in one area, it may facilitate their formation in an adjacent area. Thus, the effect of the sea-bottom relief is confined to localized areas.

On the other hand, the two basic prerequisites given above for the formation of submarine valleys conform to definite global patterns. If our purpose is given a broader formulation (i.e., if we try to encompass the largest possible number of submarine valleys and the most extensive territories of their occurrence), local factors may be neglected and we may base our analysis of the phenomenon solely on the main factors. We may then trace the principal regularities which are instrumental in the formation of submarine canyons and their distribution over the Earth. We shall now examine these main factors separately.

Fluctuations in ocean level. A deflection of the rotation axis within the Earth's body causes fluctuations of the ocean level of the entire surface of our planet. However, the magnitude and size of these fluctuations differ at different points on the globe. Variations in the magnitude and direction of the fluctuations in the ocean level conform to certain patterns. Simultaneous fluctuations are of the same sign in opposite quadrants of the globe separated by "indifferent" meridians and parallels. Following along the parallel in any quadrant the fluctuations reach their maximum values on the meridian of the shift of poles, attenuating gradually in both directions away from this meridian toward the "indifferent" meridians.

Similarly, in every quadrant, following along the meridian, the fluctuations reach their maximum values in the middle latitudes, their amplitudes diminishing toward the poles and the equator. In this case we are interested in the latter phenomenon, i.e., the regularity governing the amplitudinal variation of the fluctuations in ocean level in the meridional direction.

Table 1 lists variations in the length of the Earth's radius between the equator and the poles at intervals of 5° lat. The differences in length of every adjacent pair of radii listed in the table govern the amplitude of the fluctuation in ocean level on approaching the poles (or withdrawing from them) by 5°. For instance, the Earth's radius is 6369.6 km at a latitude

of 40°, and 6367.7 km at a latitude of 45°. The difference in the length of the radii is 6369.6 – 6367.7 = 1.9 km. This means that as the pole comes 5° closer to any point situated at the latitude of 40° the ocean level there will fall by 1.9 km. At a point situated at a latitude of 55° the approach of the pole by 5° will depress the ocean level by 1.7 km; the fall will be 1.1 km at a latitude of 15°, and so on.

TABLE 1.

Latitude, degrees	Spheroid radius, km	Fluctuation of ocean level, km
0	6378.5	
5	6378.3	0.2
10	6377.8	0.5
15	6377.0	0.8
20	6375.9	1.1
25	6374.6	1.3
30	6373.1	1.5
35	6371.4	1.7
40	6369.6	1.8
45	6367.7	1.9
50	6365.9	1.8
55	6364.1	1.8
60	6362.4	1.7
65	6360.8	1.6
70	6359.6	1.2
75	6358.5	1.1
80	6357.6	0.9
85	6357.2	0.4
90	6357.0	0.2

The third column of Table 1 lists the magnitudes of the fluctuation in the ocean level at different latitudes of the Earth when the poles approach the point (or withdraw from it) by 5°. The tabulated data can be used for plotting a graph by marking the y-axis with the values listed in the last column of the table (on any convenient scale). The resultant curve will display the pattern governing the amplitudinal variation of the fluctuations in ocean level at different terrestrial latitudes. It will be seen from Figure 1 that the maximum fluctuations in ocean level occur in the middle latitudes, decreasing at lower and higher latitudes.

In the geological past the Earth's poles shifted in several directions, and therefore it is possible to conclude that the maximum fluctuations of the ocean level in different epochs occurred in different areas of the Earth's surface situated in the middle latitudes, so that eventually large fluctuations occurred in all areas along these parallels. Areas in the polar regions and in the equatorial zone must have undergone fluctuations of considerably smaller amplitudes.

Hence it follows that conditions favoring the formation of submarine canyons by erosion must have occurred primarily in the middle latitudes. If the submarine valleys were indeed incised by rivers at low ocean levels, then they must be most numerous in the middle latitudes.

The fluctuations in ocean level are small about the poles and along the equator, and are practically zero for small deflections of the rotation axis. However, this does not indicate that appreciable fluctuations of the ocean level did not occur in the polar regions and in the equatorial zone of the Earth.

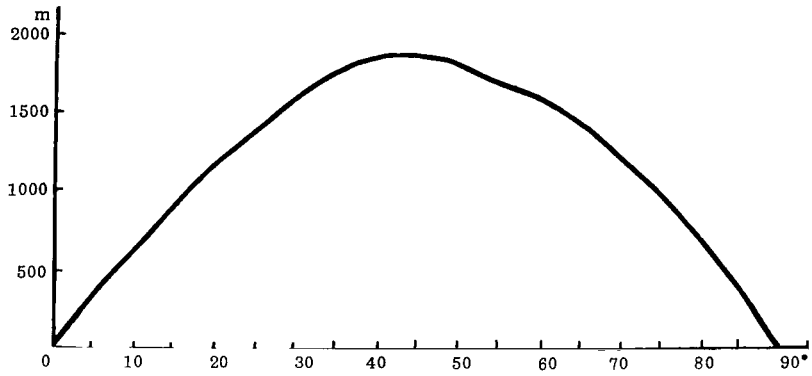


FIGURE 1. Graph of the amplitudinal variations of the fluctuations in ocean level at different terrestrial latitudes.

The depth of the largest submarine canyons (such as those discovered along the shores of North America) often reach 2—2.5 km. Assuming that these canyons were incised by rivers when the ocean level was low, we must admit a shift of the poles within 5—6°, in order to allow for a depression of the surface of the oceanic spheroid by an amount corresponding to the depth of these canyons in the middle latitudes. Such a deflection of the rotation axis would also produce appreciable fluctuations in the ocean level in the equatorial zone and in the high latitudes, although they would be far more limited than in the middle latitudes.

Although the amplitude of the fluctuations in ocean level is approximately the same within the polar circles and in the tropical zones, the prerequisites for the formation of submarine valleys in these regions are totally different. In the tropical zones, as the ocean level falls, the rivers follow the advancing coastline, incising their valleys more deeply in the process. With the characteristic abundance of atmospheric precipitation in the tropical zones it is readily seen that the erosion processes will be fairly vigorous, forming submarine canyons along the continental coasts.

The conditions created by the fall of the ocean level will be totally different in high latitudes. In case of a slight shift of poles the fluctuation in ocean level at these latitudes will be small, and the rivers will incise their valleys only to a small depth, so that the submarine canyons will soon be buried under the shifting sands after the return of the sea. If the poles shift considerably and the fall of the ocean level is large, this phenomenon will be accompanied with such a considerable drop in the mean temperatures that glaciation would inevitably occur at these latitudes. The ice sheet would cover the dry land and possibly also the sea shallows, preventing the erosive activity of the rivers.

To illustrate the above hypothesis, let us examine the possibility of the formation of the submarine valleys near the mouths of Siberian rivers flowing into the Arctic Ocean, choosing the largest rivers for this purpose, namely the Ob, the Yenisei, and the Lena. Their respective mouths lie at 67°N., 70°N, and 73°N. At these latitudes the approach of the pole through one degree causes a drop of 220 m in ocean level (see Table 1); thus, the rivers will be able to incise their valleys to a depth of 220 m, i.e., they will remain within the boundaries of the continental shelf. Such valleys may readily become buried afterward. Therefore, in order to allow for the possibility of the formation of sufficiently deep and stable submarine canyons we must assume larger shifts of the pole, of about 2.5—3°. An approach of the pole through 3° will depress the ocean level by 3×220 = 660 m, and in this case the submarine valleys will be much better preserved, provided they have been incised by the river to such a depth.

However, a drop in ocean level will also cause a drop in mean temperature.

Let us calculate the variation in mean annual temperature by the method provided by Khizanashvili /10, pp. 61—64/. A 660 m depression in the ocean level will decrease the mean annual temperature by 660/200 = 3.3 °C, while the increase in the latitude will reduce the mean annual temperature by 3×0.6 = 1.8 °C. The total temperature drop will amount to 3.3 + 1.8 = 5.1 °C. It may be assumed that a drop of 5 °C in the mean annual temperature is sufficient to cause glaciation. Evidently, favorable conditions for the formation of submarine canyons may not occur in this region even in cases of considerable shifts of the poles.

The above discussion was not intended to exclude the possibility of the formation of submarine valleys in high latitudes. The formation of canyons there may be facilitated by other factors, such as warm sea currents limiting the spread of glaciation which might result from the drop in ocean level. Furthermore, it was noted by Saks /9, p. 34/ that in high latitudes one may encounter submerged valleys of glacial or other origin. Consequently, our hypothesis should be interpreted to mean that the probability of the formation of submarine valleys is considerably lower in the polar regions than in the middle and low latitudes. This possibly explains why no submarine canyons have been discovered thus far in the Antarctic /3, 9, 11/, while their known number in the Arctic Ocean is small /9, 11/; in the Pacific basin the northernmost canyon was found at a latitude of 54°, according to Shepard /12, p. 228/.

Thus, in our discussion of the fluctuations in the level of the oceanic spheroid with respect to the possibility of formation of submarine valleys we have seen that a drop in ocean level should create conditions conducive to such formation in the middle and low latitudes of the Earth, but these conditions may not arise in high latitudes.

Distribution of atmospheric precipitation. Our second prerequisite for the formation of submarine valleys was a sufficient amount of atmospheric precipitation. As in the preceding case, we are interested in the distribution of atmospheric precipitation at different terrestrial latitudes.

We traced this distribution along four routes traversing the northern hemisphere from the pole to the equator in the most characteristic areas.* The routes were as follows: 1) along the western coast of North America, through Central America, and along the western coast of South America to the equator; 2) along the eastern coast of North America through Central America, and along the eastern coast of South America to the equator; 3) through western Europe and the Mediterranean basin, and through western Africa down to the Equator; 4) along the eastern coast of Asia, including Japan, India and Indonesia, down to the equator.** Our data on atmospheric precipitation along the above routes were taken from the instructional climatic map of the world published by the Main Administration of Geodesy and Cartography of the Ministry of Internal Affairs of the USSR in 1955.

These data were used for plotting the four graphs in Figure 2. Each of these graphs reflects the variations in atmospheric precipitation from the equator toward the North Pole along one of the routes mentioned. According to all the graphs, the maximum atmospheric precipitation falls in the equatorial zone, decreasing gradually in a northward direction, but conforming to different patterns in each of the four cases.

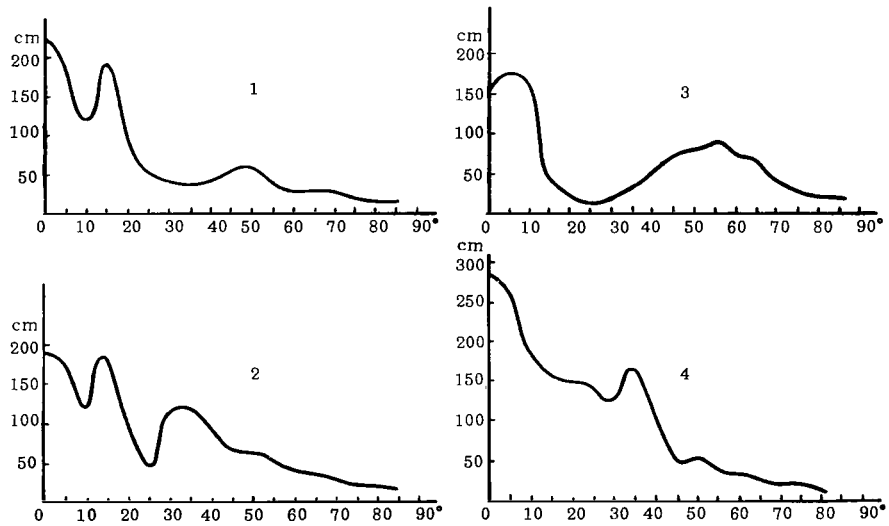


FIGURE 2. Graphs of the latitudinal distribution of atmospheric precipitation:

1. western coast of America; 2. eastern coast of America; 3. western Europe — Mediterranean basin; 4. eastern coast of Asia.

Averaged data from the above four graphs were used for plotting a combined graph (Figure 3). The values of the ordinates of this graph were computed as the arithmetic means of the corresponding ordinates of the

* The routes were chosen so that they include areas with the largest numbers of subm arine canyons.

** Being concerned with the submarine canyons in the northern hemisphere of the Earth, which have been studied most extensively, we did not deem it necessary to include the southern hemisphere in our discussion.

original four graphs. Consequently, curve B in Figure 3 does not portray the distribution of atmospheric precipitation along any single route, but reflects the general variation patterns of the amounts of atmospheric precipitation over the entire northern hemisphere.

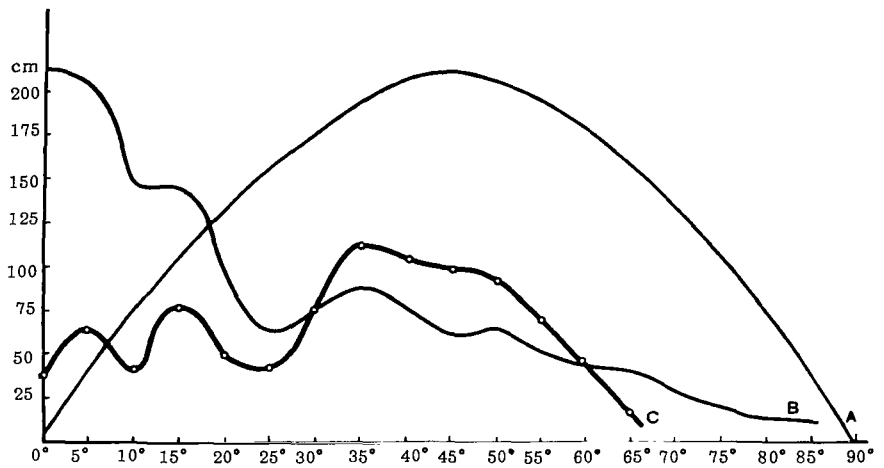


FIGURE 3. Combined graph of the distribution of atmospheric precipitation (B).

Thus we have examined separately the two main factors in the formation of submarine canyons — fluctuations in ocean level and distribution of atmospheric precipitation. In nature, however, these factors act simultaneously, and therefore we must discover the possible results of their simultaneous action. In this case we shall also use the graphic method. Curve A in Figure 3 depicts amplitudinal variations of the fluctuations in ocean level from the equator to the pole. Curve B displays the variation in the quantity of atmospheric precipitation (also from the equator to the pole). The results of their simultaneous action may be determined by simply combining these two curves.

The following introductory explanation is necessary. The amplitude of fluctuations in ocean level and the amount of atmospheric precipitation are quite different phenomena, measured in different units, so that the combination of the respective measurements is a difficult task. However, we consider it feasible to reduce both phenomena to a single scale, in their roles as prerequisites for the formation of submarine valleys. For this purpose we shall assume that the effect of both factors are approximately equal in the formation of submarine canyons. This statement is expressed graphically simply by assigning equal ordinate values to the maxima of each phenomenon. *

* We have no reason to assume that one of these factors is more important than the other; such an assumption would require special proof. Nevertheless, if either is subsequently found to be dominant, it will be sufficient to increase its ordinate accordingly in plotting the combined graph. It is readily seen from Figure 3 that such an alteration will have no appreciable effect on the general character of the combined curve. The principal change will be in the absolute values of its ordinates, which is immaterial in our case.

This somewhat arbitrary use of the graphic method is justified in view of our use of the combined curve only as a qualitative characterization of the phenomenon under consideration rather than a quantitative indicator. If considerable portions of the two graphs being added are more or less in phase, both the above conditions for the formation of submarine valleys have been met, and each intensifies the other. In this case, the probability for the formation of submarine canyons is maximum, which is expressed by the maximum ordinate value of the resultant curve.

If large ordinates of one curve correspond to minimum ordinates of the other, their combined effect will reflect the case in which absence (or insignificance) of one of the conditions lowers the possibility of the formation of submarine canyons. In the case of coincidence of the minimum values of both constituent curves nature does not provide the conditions necessary for the formation of submarine valleys. In this case the probability of their formation is at its minimum and the combined graph will drop to a minimum.

Curve C in Figure 3 has been constructed by the method described above. It combines the graphs of the distribution of atmospheric precipitation and of the amplitude of the fluctuations of the oceanic spheroid. Ordinates of this curve for each of its abscissa values were obtained by addition of the ordinates of the first two curves (A and B). Since the absolute values of the graphs are unimportant in this case, the position of curve C was somewhat lowered for the sake of convenience.

Our resultant curve reflects the combined effect of both factors — fluctuations in ocean level and amount of atmospheric precipitation — upon the formation of submarine valleys. It indicates those cases in which conditions for the formation of submarine canyons are most favorable and those in which the probability of their formation is at a minimum. It is seen from the graph that curve C reaches maximum values in latitudes ranging from 32 to 50°, indicating conditions conducive to the formation of submarine valleys. This is, in fact, the zone in which the amplitude of fluctuations of ocean level is maximum and atmospheric precipitation is abundant, so that here the two factors exhibit the same characteristics, intensifying each other.

In the zone between 50 and 55° and further north, the curve dips abruptly, signifying deterioration of conditions for the formation of submarine canyons. This is explained by the smaller amplitude of fluctuations of ocean level and a decrease in atmospheric precipitation. The curve also dips abruptly south of the zone of its maximum values, at 20—27° lat., where the probability of the formation of submarine valleys is also low. This substantiates Shepard's hypothesis on the comparative scarcity of submarine valleys at latitudes of about 30°.

Between 5 and 20° the curve has two additional maxima, indicating a recurrence of conditions favorable for the formation of submarine valleys. In this zone the amplitude of the fluctuations of ocean level is considerably smaller than in the middle latitudes, but there is a heavy increase in precipitation which more than compensates for the attenuation of the first factor. In this zone the fall in ocean level will not be very large, but the intensive erosion caused by excessive rainfall enhances the incision of canyons, so that the formation of submarine valleys becomes possible.

Curve C drops again in the equatorial zone, indicating a very low probability for the formation of submarine canyons in spite of the maximum amount of atmospheric precipitation. This is because the amplitude of the fluctuations of the ocean level approaches zero along the equator.

We have described curve C and determined the latitudes providing the most favorable conditions for the formation of submarine canyons. If our approach toward the solution of this problem is correct, then the maximum number of submarine valleys should be concentrated at the latitudes corresponding to the maxima of the curve. We must now check whether the regions providing the most favorable conditions for the formation of submarine canyons indicated by the graph are actually those of their most extensive occurrence in nature.

We must first study the distribution of submarine valleys at different latitudes. We found suitable data for solving this problem in the work of Shepard /11, 12/, Klenova /5/, and Saks /9/. Data on more than 200 submarine valleys taken from these sources are listed in Table 2. They were used for plotting the graph in Figure 4 illustrating the latitudinal distribution of submarine canyons. Each point of this curve corresponds to a known submarine canyon at this latitude. In order to render Figure 4 more informative we transferred to it also curve C from Figure 3 plotting the variation in the conditions for the formation of submarine valleys.

TABLE 2. I. Eastern coast of America

No.	Name of canyon	Number	Latitude
1	Tay Gully	1	43°50' N
2	Corsair	1	41° N
3	Lidoniya	1	40°25' N
4	Oceanographer	1	40°20' N
5	Welker	1	40°20' N
6	*	1	40°10' N
7	Hydrographer	1	40° N
8	Witch	1	39°50' N
9	Block	1	39°50' N
10	Hudson	1	39°30' N
11	*	1	39° N
12	Wilmington	1	38°30' N
13	Baltimore	1	38° N
14	Washington	1	37°20' N
15	Norfolk	1	37° N
16	Mississippi	1	29° N
17	De Soto	1	29° N
18	Northern coast of Cuba	1	21°30' N
19—20	Group of Puerto Rico Is.	2	18° N
21	Windward Is.	1	16° N
22—23	São Francisco group in Brazil	4	4°30'—10' S
26—29	Rio de Janeiro group	4	20—23° S
30	Uruguay	1	35° S

II. Western coast of America

No.	Name of canyon	Number	Latitude
31	Bering	1	54° N
32—35	The Aleutian group	4	50—52°30' N
36	Fraser [River mouth]	1	48°30' N
37	*	1	48°10' N
38	*	1	47°50' N
39	*	1	47°30' N
40	*	1	47°10' N
41	Grays Harbor	1	46°50' N
42	Willapa (Cape Lidbenter)	1	46°30' N
43	Columbia [River]	1	46°10' N
44	Trinidad [Light house]	1	41°10' N
45	Eel	1	40°40' N
46	Mattole	1	40°20' N
47	Spanish canyon	1	40°10' N
48	Pt. Delgada	1	40° N
49	Noyo	1	39°30' N
50	Stuart's point	1	38°30' N
51	Bogeda [Head]	1	38°10' N
52	Pioneer	1	37°20' N
53	Ascension	1	37° N
54	Monterey	1	36°40' N
55	Carmel	1	36°30' N
56	*	1	36°10' N
57	Pt. Sur	1	36° N
58	Pottington	1	35°50' N
59	Lucia	1	35°20' N
60	*	1	35°10' N
61	*	1	35° N
62	*	1	34°20' N
63	Pt. Arguello	1	34°15' N
64	*	1	34° N
65	Dyum	1	34° N
66	Redondo	1	33°50' N
67	*	1	33°40' N
68	*	1	33°10' N
69	*	1	33° N
70	Scripp	1	32°50' N
71	Los Coronados	1	32°30' N
72—74	North-Mexican group	3	22°30'—25° N
75—78	North-Mexican group	1	21° N
		3	18—20° N
79—82	South-Mexican group	4	15°30'—17°30' N
83—85	Guatemala group	3	13°—14°30' N
86—89	Panama group	4	7°30'—10° N
90—91	Peruvian group	2	16—17° S
92—97	Chile group	3	22—25° S
	(Maipo)	3	32—36° S

III. Eastern and southern Asia

No.	Name of canyon	Number	Latitude
98—106	Far Eastern group	5	45°—46°30' N
		4	42°30'—44° N
107—110	Korean group	2	40°30'—42° N
	(Pisan canyon)	2	38—40° N
111—113	Toyama Wan group	3	37° N
114	Sagami	1	35°10' N
115	Tokyo	1	35°5' N
116	Sunosaki	1	34°50' N
117	Suruga Wan group	1	34°30' N
118—121	Formosa group	2	22°30'—24° N
	(Chotsui Pit)	2	21—22° N
122	Balintang	1	19° N
123	Calayan	1	19° N
124—135	Luzon group: (Laoag)	4	17°30'—19° N
	(Mainganan)	6	15°—17°30' N
	(Manila)	2	14°—15° N
136	Ganges	1	21° N
137—142	Ceylon group	3	7°30'—9° N
		3	5. —7. 30' N
143	Indus	1	23° N
144	Oman coast	1	17°20' N

IV. Africa

No.	Name of canyon	Number	Latitude
145—150	Algerian group	6	37° N
151—155	Egyptian group (Nile)	5	32° N
156—158	Syrian group	3	33—35° N
159—164	Western group	1	8—10° N
		2	10°—12°30' N
		1	12°30'—15° N
		2	15°—17°30' N
165—168	Somali group	3	5°—7°30' N
		1	7°30'—10° N
169	Bight of Benin	1	5° N
170	Kamoé [Inlet]	1	5° N
171—172	Equatorial group	1	0°
		1	30' S
173	Congo	1	6° S
174	Bengo	1	8° S
175—181	Mozambique group (Mocimboa)	7	8°—16° S
182—185	Sul do Save group	4	20—25° S
186—188	South African group	3	33—35° S

V. Europe

No.	Name of canyon	Number	Latitude
189—190	Norwegian group	2	67°30' —70° N
191—193	Riviera group	3	43—44° N
194—201	Corsican group	3	42°30' —43° N
		5	41°—42°30' N
202—204	Group of Sardinia Is.	1	41° N
		2	39°—40° N
205—208	Italian group	2	40—42° N
		2	38°—39°30' N
209—211	Sicilian group	2	38°30' N
		1	37° N
212—213	Riviera di Levante	2	41—42° N
214	Strait of Gibraltar	1	36 —37° N
215—216	Tajo [Tagus]	1	38°30' N
	(Baia de Setubal)	1	38°20' N
217—218	Nazaré	1	39°30' N
		1	39°50' N
219	Douro	1	41°30' N
220—224	Biscay group (Capbreton)	5	43°40' N

VI. Oceania and Australia

No.	Name of canyon	Number	Latitude
225—227	Hawaii group	3	21—22° N
228	New Guinea	1	8° S
229—233	Australia:		
	Cape Steep Point	1	26° S
	Perth	2	32° S
	Kangaroo Is.	1	36° S
	Southeastern coast	1	37° S
234—235	New Zealand	1	37° S
		1	42° S

* Information on nameless canyons was borrowed from Shepard's map /11, 12/.

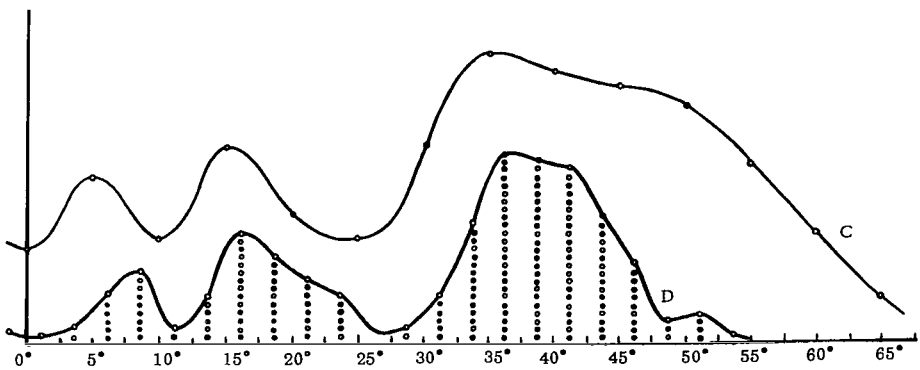


FIGURE 4. Comparison of curve C, indicating favorable conditions for the formation of submarine valleys, and curve D, representing the latitudinal distribution of these valleys.

It is now possible to check, by comparing the two curves, whether the maximum occurrence of submarine canyons is actually found within the regions that should provide the most favorable condition for their formation according to the graph. In Figure 4, the great similarity of the two curves, both in main features and in details, is immediately apparent. For example, both curves reach their maximum values in the middle latitudes, in the zone 30 to 50°; each reaches a secondary peak in the latitudes 13 to 18°, somewhat lower than the maximum value. In both cases there is a depression between these two peaks in the region of latitudes 25 to 27°. The minimum values of both curves occur on the equator and at latitudes higher than 60 to 65°, and so on.

It is our opinion that the similarity of the two curves cannot be accidental, and that we are justified in assuming that a causal relationship exists between the phenomena illustrated by the graphs. Similarity of the curves shows that the assumed pattern of the formation of submarine valleys is to a certain extent reflected by the actual distribution of canyons. The hypothesis that the genesis of submarine valleys is actually related to fluctuations in ocean level due to deflections of the rotation axis within the Earth evidently reflects, somewhat, the real conditions.

The distribution curve for submarine valleys was plotted from data that we found in scientific literature. Obviously new submarine canyons will be discovered in the course of time and their plotting on the graph may modify it to some extent. Our final judgement on the similarity between the curves of the most favorable conditions for the formation of submarine canyons and their actual distribution must be withheld until curve D has been marked with all submarine canyons actually existing in nature. Nevertheless, our data was sufficiently extensive to reveal the general distribution pattern of submarine valleys. Probably the nature of this pattern will not be significantly affected by supplementary information on new canyons. In order to trace the correlation between the phenomena illustrated in Figure 4 the curves need not resemble each other in all details. If, after the accuracy of the graphs has been improved, the curves retain their similarity with respect to their principal features (such as their maxima in the zones 30 to 50° and 5 to 20° and the well-marked depressions between them), we shall be justified in assuming that the phenomena reflected by these curves are in some way correlated and that the conclusions reached in this paper provide some knowledge of the real conditions.

REFERENCES

1. Atlas mira (World Atlas), Moskva. 1954.
2. BERG, L.S. Podvodnye doliny (Submarine Valleys). — Izvestiya Vsesoyuznogo Geograficheskogo Obshchestva, Vol.78, No.3. 1946.
3. DOBRYNIN, B.F. K voprosu podvodnykh kan'onov (Submarine Canyons). — Uchenye Zapiski MGU, No.48, Geografiya. 1941.
4. KLENOVA, M.V. Pogruzhennye beregovye linii Barentseva morya (Submerged Coastlines of the Barents Sea). — Trudy Sovetskoi Sektsii Mezhdunarodnoi Assotsiatsii po Izucheniyu Chetvertichnogo Perioda, No.4. 1939.

5. KLENOVA, M.V. Geologiya morya (Marine Geology). – Moskva, Uchpedgiz. 1948.
6. LINDBERG, G.U. Geomorfologiya dna okrainnykh morei Vostochnoi Azii i rasprostranenie presnovodnykh ryb (Bottom Geomorphology of East Asian Marginal Seas and the Distribution of Freshwater Fish). — Izvestiya Vsesoyuznogo Geograficheskogo Obshchestva, Vol.78, No.3. 1946.
7. LINDBERG, G.U. Sovremennoe sostoyanie problemy proiskhozhdeniya podvodnykh dolin (Current Views on the Origin of Submarine Valleys). — Voprosy Geografii, No.3. 1947.
8. LINDBERG, G.U. O prichine sokhrannosti mikrorel'efa sushi na dne morya (Causes of the Preservation of Continental Relief on the Sea Bottom). — Izvestiya AN SSSR, Seriya Geograficheskaya i Geofizicheskaya, Vol.12, No.4. Moskva. 1948.
9. SAKS, V.N. Zagadka podvodnykh dolin (The Riddle of Submarine Valleys). — Priroda, No.9. 1948.
10. KHIZANASHVILI, G.D. Dinamika zemnoi osi vrashcheniya i urovnei okeanov (Dynamics of the Earth's Rotational Axis and of Ocean Levels), Tbilisi. 1960.
11. SHEPARD, F.P. and C. BIRD. Submarine Canyons: Their Distribution and Long Profiles. [Russian translation. 1941.]
12. SHEPARD, F.P. Submarine Geology. — Harper, New York. 1948. [Russian translation. 1951.]
13. SHUMSKII, P.A. Sovremennoe oledenenie sovetskoi Arktiki (Present-day Glaciation of the Soviet Arctic). — Voprosy Geografii, No.4. 1947.

S. Yu. Brodskaya

PALEOMAGNETIC RESEARCH IN THE USSR

Paleomagnetism is a new field of Earth science which lies on the boundary between geophysics, geology, and the study of ferromagnetism. Research in this field is becoming a matter of ever-increasing interest, since it gives us information on the following important subjects: 1) the history of the Earth's magnetic field and the variations in this field throughout geological time; 2) the relation between these field variations and phenomena taking place during the course of the Earth's evolution. In addition to this, paleomagnetic research opens whole new vistas in geological stratigraphy and geochronology.

Paleomagnetic studies are developing with particular intensity in the Soviet Union. In order to coordinate the research in this field, a Paleomagnetism Commission was set up at the Shmidt Institute of Earth Physics early in 1959. This commission, which is a part of the Division of Physics and Mathematics of the USSR Academy of Sciences, periodically holds meetings and conferences at which findings in the field of paleomagnetism are presented.

The Fourth All-Union Conference on Paleomagnetism was held at the Institute of Earth Physics from 31 January to 6 February 1961, with 160 delegates, representing 60 institutions in 28 cities of the Soviet Union, taking part; 26 scientific reports were read and 20 communications were presented. At the Third All-Union Conference on Paleomagnetism, held the previous year, only 58 delegates from 13 Soviet cities were present. These figures indicate how much the interest of geologists and geophysicists in problems of paleomagnetism has grown in recent years.

The reports dealt with the following general subjects: 1) the magnetic field of the Earth in the past and the correlation between geological strata; 2) the different geological-geophysical conditions under which ferromagnetic rocks are formed; 3) the physical fundamentals of paleomagnetism; 4) reverse magnetization; and 5) instrumentation problems.

The following survey reports were presented at the conference: "The Physical Fundamentals of Paleomagnetism," by G. N. Petrova and B. M. Yanovskii; "Paleomagnetic Studies in Stratigraphy and Geochronology," by A. N. Khramov; "The History of the Geomagnetic Field on the Basis of Paleomagnetic Research," by A. G. Kalashnikov; and "A Review of Modern Geotectonic Theories, Particularly Theories of Horizontal Shifting of the Earth's Crust," by P. N. Kropotkin. The first report was actually two separate studies in one. In his portion Yanovskii gave a theoretical explanation of the remanent magnetization in certain rock types. He

discussed the conditions under which the remanent magnetization changes and also in cases in which, despite a change in the crystal lattice of the rock, the magnetization may be considered to be unchanged.

Petrova's report dealt with the basic principles and the limits of application of all the various laboratory methods for determining the stability of the remanent magnetization of rocks. This subject is a very vital one, since magnetologists cannot as yet distinguish between the primary and secondary magnetization of all rocks. Thus, methods must be worked out for obtaining samples in which the direction of the magnetization is practically unchanged.

Khramov's report was of particular interest to geologists. It presented some results of paleomagnetic studies in stratigraphy and geochronology, and it also pointed out some new applications of paleomagnetic research in stratigraphy, paleogeography, paleoclimatology, and tectonics. In particular, the possibility of constructing a geochronological scale by paleomagnetic methods was considered.

The report of Kalashnikov constituted a first attempt toward generalizing all the various paleomagnetic conclusions concerning the position of the magnetic pole during past geological epochs, according to the data of Soviet and non-Soviet investigators. This report included a composite table, compiled using Soviet data, in which material submitted at the present conference was also used.*

The various modern geotectonic theories, in particular the theory of horizontal shifting of the Earth's crust, were discussed in detail by Kropotkin. After considering both the fixed-crust and moving-crust hypotheses, the author concluded that in general the contraction theory is being replaced by theories assuming a moving crust. Kropotkin also noted that geophysical methods (and the magnetic method in particular) make it possible to ascertain the dimensions and the mechanism of the crustal motion, a problem which cannot be solved unambiguously by geological methods alone.

The findings of paleomagnetic studies of deposits of different ages from various parts of the Soviet Union were discussed in the first group of reports. The regions covered in these studies were: the Russion Platform, the Ukraine (including the Crimean region), Armenia, the Urals, Kazakhstan, the southern part of the Siberian Platform, and the central part of the Krasnoyarsk Territory. This group also included a report on the study of secular variations using archeomagnetic methods.

A. N. Khramov and his coworkers presented the results of some new affirmative tests of making up composite key sections of rocks, using the paleomagnetic method. These tests were used to correlate the deposits laid down over vast territories.

A paleomagnetic analysis of sedimentary strata from the Upper Devonian was presented by T. I. Lin'kova. These studies indicated that rotation of the geomagnetic field took place during the Devonian, since directly and reversely magnetized rocks were found to have identical ferromagnetic compositions. The pole positions computed on the basis of these measurements agreed well with the data of other authors.

* Kalashnikov, A. G. Istoriya geomagnitnogo polya (po paleomagnitnym dannym) (The History of the Geomagnetic Field (According to Paleomagnetic Data)). — Izvestiya AN SSSR, seriya geofiz., No. 9. 1961.

G. I. Kruglyakova and A. N. Tret'yak reported on a series of measurements of the remanent magnetization of rocks from the Cambrian, Ordovician, Silurian, Devonian, and Carboniferous periods; the rocks studied were found in the Ukraine. The coordinates of the poles were calculated for the corresponding epochs. Ts. G. Akopyan discussed the stratigraphical correlation and the differentiation of Cenozoic volcanogenic formations in the Armenian SSR and in the adjacent parts of the Lesser Caucasus Mountains, on the basis of paleomagnetic measurements.

V. V. Kochegura and B. Sh. Rusinov gave the results of their study of reverse magnetization in Devonian porphyrites. It is these authors' opinion that the value of Q drops exponentially with age, and that thus the Q factor can serve as a criterion for the stability of rocks. The position of the pole during the Carboniferous period, as determined by Gzhel' clays from the region around Moscow, was discussed by O. L. Andreeva. These clays turned out to be exceptionally stable, due to the presence in them of finely dispersed hematite. The vector field of the remanent magnetization was found to be very uniform (confidence-circle radius of 1°).

V. F. Davydov made a study of the remanent magnetization of traprocks in the southern part of the Siberian Platform. On the basis of computed pole positions, this author related some of the traprocks to the period between the Cambrian and the Carboniferous and some to the period between the Carboniferous and the Triassic. The conclusions of the author, however, are somewhat dubious.

The results of a study of Devonian rocks from the central part of the Krasnoyarsk Territory were presented by A. Ya. Vlasov and others. In this study, which from the methodical point of view was on a very high level, the average pole position was computed for the rocks in question.

I. A. Rezanov attempted to show in his report that horizontal movements of the continents could not have taken place. The plots of polar wandering obtained on the basis of measurements of rocks from different continents do not coincide, and this fact led to the continental-drift hypothesis. Rezanov questions the latter hypothesis, however, since, in his opinion, the spread in the pole positions for different continents is the result of a systematic error, probably introduced by a reversal of the magnetization of the rocks during subsequent periods, and thus it does not constitute evidence for continental drift.

S. P. Burlatskaya and G. N. Petrova solved the problem of the recovery of the geomagnetic field in the past, on the basis of archeomagnetic studies. Samples from the city of Tbilisi covering the period from the sixteenth century to the present were measured. As a result of these studies, the first Soviet curves of the change in direction (orientation) of the geomagnetic field, and also of the change in absolute magnitude of the field, were obtained.

These reports, particularly that of Davydov, provoked a lively discussion. The need for a more accurate geological referencing of the samples, and thus of the measurements as well, to strata and formations was pointed out. Certain geologists criticized the conclusions of paleomagnetism which lead to the hypothesis of continental drift, but this criticism was made with respect to the data of modern geology and not with respect to the correctness or incorrectness of the methods of paleomagnetism.

A final solution of this problem will be possible only after careful paleomagnetic studies in which the sections are very accurately pinpointed to regions in which continental movements definitely did not take place. Such sections may be found on the Russian, Siberian, and Chinese Platforms. The Paleomagnetism Commission was accordingly assigned the task of organizing studies designed to solve this problem.

The reports in the second group dealt with the geophysical conditions accompanying the formation of specific types of rocks. A. G. Komarov considered the changes which take place in extrusive rocks after their formation. For platform formations, magnetic and structural aging takes place, without any variation of the chemical composition of the rock. For mobile belts, the initial stages of metasomatic metamorphism are observed. These are accompanied by the addition of considerable quantities of magnesium and ferrous iron, by the loss of alkalis, ferric iron, and silicon, and by a change in the magnetization of the rocks as a function of the chemical effects.

A. N. Shmeleva studied the magnetization of sedimentary rocks, both in a natural state and after reprecipitation, and she showed that secondary magnetization can be distinguished by this means. The precipitation was carried out during the course of a year, with deposit formation at a pressure of 1.5 kg/dm^2.

The effect of consolidation of the remanent magnetization of artificially precipitated sediments was investigated by A. Ya. Vlasov and his coworkers. It was found that the consolidation brought about by a vertical pressure of 1666 kg/cm^2 reduced the inclination by almost 10°; lateral pressures resulted in an increase of the inclination. The artificial sediments possessed high magnetization stability, with respect to constant and variable magnetic fields and also with respect to temperature variations.

T. A. Martynova studied changes in the magnetic properties of ferruginous quartzites of the Kursk magnetic anomaly. It was found that the magnetic susceptibility and the remanent magnetization decreased at the boundary of the oxidation zone (in the weathering crust). The relation between the amount of remanent magnetization of a rock and the degree of its metamorphism was established. This same subject was treated by V. I. Zavoiskii and Z. A. Krutikhovskaya, who made a study of iron quartzites from Krivoi Rog. These investigators reported that the magnetization direction depends both on the rock structure and on the orientation of the eutaxitic structure of the rock.

The magnetization of rocks in the alkali massif of the part of the Ukrainian Shield in the vicinity of the Sea of Azov was studied by N. P. Mikhailova. The remanent magnetization was found to depend on the susceptibility, Q being a quantity which characterizes the structure of the rock and its position in the massif. However, it is doubtful whether this Q factor can be used for age correlation.

During the discussion of the foregoing reports, it was suggested that further studies of artificially precipitated rocks be made, and that particular attention be given to the reprecipitation conditions (flow, salinity of water, and particle dimensions).

The third group of reports dealt with the physical fundamentals of paleomagnetism. G. N. Petrova justified her suggestion that the magnitude of the so-called disruptive field be taken as a stability parameter. In addition, she described the properties and limits of the temporary magnetization of ferromagnetic rocks.

The viscous magnetization of rocks was investigated by L. E. Sholpo, who suggested that the viscous magnetization during any time period be computed by extrapolation. Laboratory studies showed that magnetic viscosity is more evident in rigid materials and that it depends on the ferromagnetite concentration. The author did not elaborate upon the latter factor.

S. Yu. Brodskaya and M. A. Grabovskii presented the results of a study of the magnetic parameters of artificial rocks. The dependence of these parameters on the concentration of ferromagnetic components in one-component and two-component media was investigated. Formulas for calculating the magnetization of one-component and two-component samples were derived for all concentrations. There was good agreement between the experimental and calculational data.

The report of A. G. Zvegintsev and A. Ya. Vlasov contained the findings of a study of thermal magnetic hysteresis in various fields, over a temperature range from 20 to 700°C.

V. I. Bagin presented the results of his study of the magnetic properties of hematite. According to Bagin's data, this mineral has very high magnetic stability. The thermoremanent magnetizations of hematite and magnetite are commensurable.

During the discussion of these reports it was noted that viscous and temporary magnetization of rocks are both relaxation phenomena, but that the relaxation coefficients of the two are different. It was also noted that the main task at present is to work out improved methods for distinguishing the primary magnetization or else methods for magnetic cleaning. During the discussion it became evident that the paleomagnetologists present disagreed sharply with respect to the possibility of making use of the Q factor. V. V. Kochegura, A. G. Komarov, and others consider that Q can definitely be used to determine age and, in addition, that it is a very convenient stability criterion. Others (N. M. Efremova, N. P. Mikhailova, G. N. Petrova, and D. M. Pecherskii) disagreed, and they pointed out that the value of Q depends on the magnitude of the disruptive field, so that only the ages of rocks with specific ferromagnetic components can be determined according to the value of Q. Pecherskii demonstrated in his report that the values of Q for rocks of identical ages and compositions may differ by a factor of ten or more, depending on the conditions under which the rocks were formed.

The fourth group of reports dealt with reverse magnetization in rocks. B. V. Gusev made a study of ultrabasic rocks exhibiting reverse magnetization. When such rocks were heated up to 800°C and then cooled down in a 0.6-oersted field, only a single, normally magnetized component with T_K = 300 to 400° appeared. After aging of the samples for times ranging from 10 days to 2 years, self-reversal of the remanent-magnetization vector took place; it was established that in this case a new magnetic phase with T_K = 600° was initiated.

The report of V. V. Kruglyakov included data on the behavior of hematite and titanomagnetites under supergene conditions. Decomposition of these minerals is observed under such conditions and the magnetite separates out; reverse magnetization may also occur. Consequently, titanomagnetites cannot always be used for paleomagnetic research. V. V. Metallova described some studies which were made with samples

of reversely magnetized traprocks from the Siberian Platform. She demonstrated that the reverse magnetization in this case was related to the composition of the rocks, rather than to the direction of the geomagnetic field.

A. A. Smelov and L. P. Zhogolev carried out an analysis of the remanent magnetization in rocks from Kazakhstan. Both positively and negatively magnetized rocks were studied. These investigators attribute the reversal of the magnetization to suitable rock composition and to rapid cooling of the rocks. In the discussion of these reports the need for further study of the self-reversal of the magnetization of rocks was stressed; it was also noted that criteria enabling the prediction of self-reversal must be worked out. V. V. Kochegura questioned the conclusions of Smelov's study of the rocks from Kazakhstan, and he pointed out that the reverse magnetization of these rocks is related to rotations of the geomagnetic field rather than to self-reversal.

Several reports were read at the meeting on problems of instrumentation, which was organized on the initiative of the participants of the conference. Raising the sensitivity of magnetometers by means of resonance techniques is a basic instrumentation problem.

The Fourth Conference on Paleomagnetism made it clear that Soviet studies of the remanent magnetism of rocks are developing rapidly and leading to significant conclusions. A resolution was adopted, in which the main tasks related to paleomagnetism which still have to be carried out by geophysicists and geologists were cited. Two of the most important of these tasks are: making a detailed study of individual stages in the history of the geomagnetic field; and studying certain stratigraphical sections, with a view toward using paleomagnetic data for geological correlation.

V.B. Neiman

A COMPARATIVE DESCRIPTION OF HYPSOGRAPHIC DATA OF SOME PLANETS

The hypsographic curve and the frequency curve of heights and depths of the Earth, both externally very simple but plotted after gross generalizations, were first constructed by A. Penk in 1894 /7/ and W. Franbert in 1911 /5/. Subsequently, as new materials became available (the lack of data was at first particularly acute for the description of oceans), the curves were gradually made more accurate. The curves for other planets, for obvious reasons, have not yet been plotted. One of the first attempts in this direction is the plotting of the frequency curve for heights and depths on the visible side of the Moon /3/.

To disclose the deeper meaning inherent in these plots, it is advisable first to touch on some questions of the relationship between the relief and the inner structure of the epigene strata of the Earth. While small, local forms of relief are often only indirectly influenced by tectonic factors, structures of first and higher orders* generally have any one of their structural elements participating in the topography (with the exception of substructures).

What is the reason for this feature of large topographic forms? The answer is that the inner structure develops in each case almost autonomously, and therefore differ greatly for different territories.

These differences are not only morphological and structural, but also genetic and historic-geological. While comparatively small structures differ mainly in that they are somewhat more elevated or somewhat more sunken relative to neighboring parts, large elements are characterized by sharply differing intensity of volcanic and metamorphic processes, by the degree of metamorphization, by a different composition, etc. These zones also differ qualitatively in their types of motion, which depend on "time and space coordinates".

Seas and mountains, oceans and plains... With the exception of plains, these formations are "defective" from the viewpoint of the "orthodox" geologist, since they are devoid of the upper, granite part of the crust. For example, in marine basins, which are often prototypes of geosynclines (e.g., the southern part of the Caspian, Black Sea, Red Sea, Gulf of Mexico, etc.), thick strata of sedimentary rocks (up to 25 km on the bottom of Caspian Sea) lie directly on a basalt substratum**. In mountains these strata often form folds whose structure sharply varies even on comparatively

* Structures of first order include large lowlands (such as the North Caspian syneclise), shelves (Ukrainian, Baltic), mountain systems (the Caucasus, the Carpathians), etc.

** Basaltic crustal substratum does not show on continents. Its existence is inferred from indirect indications.

small stretches. At the bottom of the oceans there are virtually no sedimentary strata, and water comes almost in direct contact with basalt, and sometimes apparently peridotite, masses. There are thus great differences in the structures of different large zones. These vertical-structural differences must obviously be reflected also in the relief of these zones.

We have grown so accustomed to the present-day aspect of our planet that without much conscious thought we try to fit all the enormous volume of historic-geological data available into the Procrustean bed of the contemporary terrestrial structure. On the other hand, the existence of zones which differ both in structure and in age points to diverse stages of evolution of the planet Earth.

Of considerable significance in the analysis of this evolution are such generalized characteristics of the relief as the hypsographic curve (Figure 1) and the frequency curve of heights and depths (Figure 2). The former gives a generalized, averaged profile of the planetary surface—from highest mountains to deepest troughs. Here heights and depths are laid off on the ordinate, and the corresponding areas are marked on the abscissa (from left to right). When plotting the curve, each consecutive, lower-lying area is added to the preceding value.

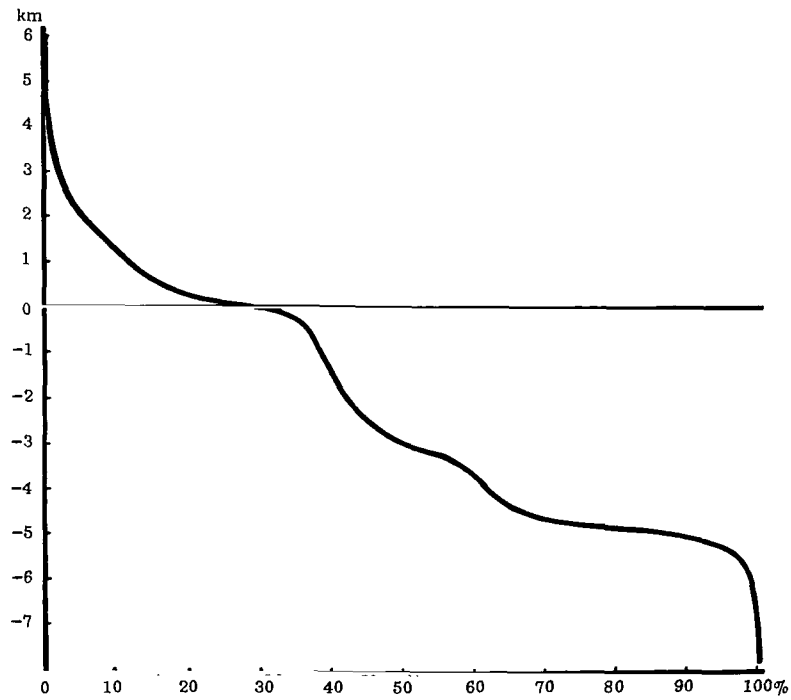


FIGURE 1. Hypsographic curve of the Earth.

The frequency curve gives the distribution of heights and depths at certain intervals (for the Earth, every 200 m). Since this curve is more characteristic than the hypsograph, we shall refer to it first (see Figure 2). Superficially, this curve should have only morphological meaning. However, this is not so. The frequency curve can help in answering the following question: is there any genetic relation between the principal formations of the Earth's surface—the continents and the oceans; are the oceans formed by continents, or vice versa? The only answer possible here is that these are entirely unrelated formations, and that the oceans appeared much later than the continents.

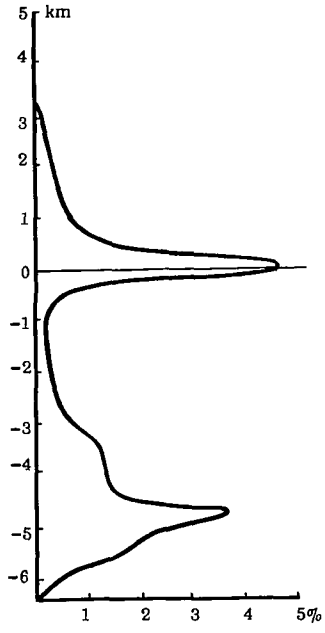


FIGURE 2. Frequency curve of heights and depths for the Earth.

Indeed, the minimum observed on the frequency curve between the two maxima closely approaches the ordinate axis, i.e., it is very small, and consequently the transition from the upper part of the curve characterizing the continental heights to the lower part, which characterizes the depth of the oceans, is insignificant: otherwise, intermediate heights would have been abundantly represented. Their virtual absence gives firm evidence to the effect that the principal formations of the Earth's surface are genetically unrelated. This is repeatedly confirmed by the abruptness of transition from continental structures to the oceans, via the steep continental slope, which is observed not only at the fringes of continents, but also surrounding any of the large islands.

These facts suffice to prove, without touching on the entire body of geological, geophysical, astronomical, and other evidence, that the oceans, in view of their comparatively young age relative to the age of the Earth as a whole (100-150 million years as compared to several billion), are neoformations which originated independently of the continents owing to surface accretion in these depressions, at a lower level than the continents. This position is consistent with the conception of an expanding Earth, advocated by the author of the present article /2/.

To conclude the analysis of contemporary terrestrial hypsometry, we should observe that in some oceanic zones, particularly in the Pacific Ocean, there exist vast leveled portions of the bottom generally situated at a depth of 5-6 km (as distinct from the broken relief of the shallower parts). This explains the third, lowest stage of the hypsographic curve.

We can make a suggestion (there is still no direct evidence for or against that this part refers to the exposed (that is, covered by a thin sedimentary layer) peridotitic shell of the Earth. This assumption becomes more plausible when we compare the general relief of the ocean with the topography of other planets, but mainly of the Moon /3/.

Until recently this problem was not even formulated in the most general of terms, but proceeding from a comparative analysis of hypsographic data

for the planets we may gain insight into the historical stages through which our own planet has passed.

To plot the frequency curve of heights and depths for the Moon, the author studied the available hypsometric (physical) maps for this body. It turned out that besides the chart compiled over 60 years ago by Franz /6/, there only exists the map of G. Schrutke-Rachtenstamm /8/. However, the latter author, who used an enormous body of data, failed in this interpretation—in his charts he made no allowance for the actual outlines of the "maria", which is highly essential in view of the scant data available. The last chart was therefore redrawn by the author of the present article and presented at the International Symposium on the Moon, held in December 1960 in Leningrad /3/.

A calculation of areas in each height interval on this map made it possible to plot for the Moon the frequency curve of heights and depths, and then to draw—especially for this article—the lunar hypsographic curve (Figures 3 and 4 and Table). In all plots the bottom of crater Mösting A was assigned zero level.

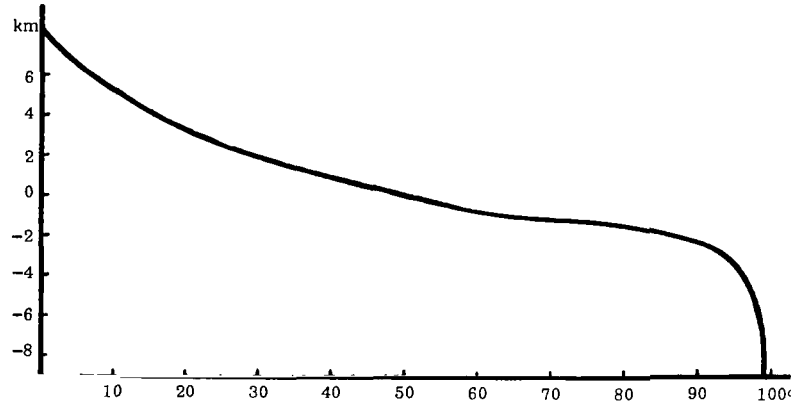


FIGURE 3. Hypsographic curve of the Moon; the side facing the Earth.

However, before proceeding with our analysis—mainly an analysis of the frequency curve, it being the more characteristic of the two—we should emphasize that of necessity the accuracy of the plots is low: the isolines were drawn every 2 km. Consequently, flexures of relief, even the boundaries of lunar maria and continents, are inadequately represented in our graphs.

The lunar frequency curve, in distinction from the terrestrial curve, has a single maximum (see Figure 4). A study of spectroscopic properties of lunar rocks leaves no doubt that this curve is analogous to the curve for the ocean bottom of the Earth /3/. Like the ocean bottom, the lunar formations are apparently made of basic (lunar continents) and ultrabasic (maria) rocks. While accumulation of more accurate data on terrestrial oceans will enable a trimodal curve to be plotted for the Earth in the near future, the lunar curve will eventually have two maxima. These secondary maxima, however, will not be as sharp as the present ones.

A comparative analysis of the two curves thus leads to certain general

questions. Did the frequency curves always have an appearance similar to their present one? The answer, of course, is no. In particular, on the Earth in past epochs (prior to the Mesozoic) no oceanic depressions apparently existed; they formed subsequently in extension zones of the primary crust /2/. Up to that stage, only small, so-called epicontinental seas existed on the Earth*. The frequency curve corresponding to that time should only have the upper "continental" peak.

Table of occurrence of heights and depths on the visible side of the Moon

Height and depth intervals, km	Area, %
Over 6	2
+ 6 + 4	7
+ 4 + 2	13
+ 2 0	15
0—2	35
—2—4	22
—4—6	4
—6—8	1
Below —8	1

An analysis of data on the evolution of the Earth's crust shows that it breaks from time to time /4/, which leads to accumulation of sedimentary strata in fault zones; this stage gives way to orogenesis, followed by aging (erosion and leveling) of the mountains, and finally their conversion to plain, platform regions. Consequently, the relief of the sial crust periodically grows complex, and then simple. At certain times, the "fault" may expose the basalt substratum, which is then covered with sediments and no longer shows on the surface. As a result, the frequency curves of earlier epochs apparently alternated between one and two maxima. Moreover, in distinction from the recent curve, the oceanic level played a highly inferior role. This is proved by the fact that sediments were then deposited in shallow seas, while abyssal formations are known in a few, generally questionable instances. How does this historical outlook help in characterizing the surfaces of other planets?

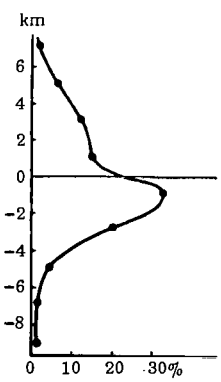


FIGURE 4. Frequency curve of heights and depths for the Moon; the side facing the Earth.

Let us start with Mars. Its surface, as we know, is relatively plain, with the exception of the dark belts of the maria. Are these analogs of the oceanic bottom or of the great terrestrial plains? In spite of the large distance to this "near" planet, we apparently can give a fairly definite answer to this question. The point is that rose-colored rocks prevail on Mars, occupying some 60-70% of its surface. Their rose color is generally regarded as a desert varnish. However, the Martian conditions are far from desert: the

* It seems that the main bulk of water filling the oceanic depressions originated at a later time, during the actual formation of the oceans.

planet's average temperature is far below the freezing point. It is therefore logical to attribute the color of the Martian surface to acidic or related rocks, i.e., most of the crust of Mars can be regarded as an analog of the terrestrial granite crust. In places, however, e.g., in maria which are obviously lower than the continents (which is the reason for the accumulation of moisture in them), the main surface component is apparently the crustal "basalt" of Mars. An analysis of Martian topography thus shows that the main peak of the frequency curve will be accompanied by a second peak, which, though an analog of the oceanic (basalt) bed of the terrestrial oceans, is much less developed than the second terrestrial maximum (its magnitude is similar to what has apparently been the case for the Earth in past epochs).

What is the position of Mars relative to the other planets? The Moon, the smallest of well-known planets, has a diameter of 3.5 thousand km and a differentiated basic-ultrabasic crust. Mars is 6.7 thousand km in diameter and is characterized by essentially different conditions than the Moon. Finally, the Earth, with its diameter of 12.7 thousand km, has a highly differentiated three-layer crust.

Applying the extension hypothesis /2/, we may find the reason for the differences. The crustal differences of the three planets are consistent with differences in their respective sizes, which in turn are functions of the inner development of the planets. Briefly this can be summarized as follows. The granite crust has not developed yet on the Moon because of the small size of this planet. It apparently forms on planets reaching a size of the order of 6 thousand km, whose material acquires new physical properties. This should naturally lead to a transformation of the hypsograph which, from a curve characterizing a peridotite-basalt planetary surface (e.g., the Moon), will change to a curve typical of planets with "granitized" crusts (Mars, Earth).

Depending on the particular stage of evolution of the granite part of the crust at which a given planet is observed, the latter can have a poorly differentiated (as now on Mars) or a highly differentiated (as on Earth) surface. During the evolution from the poorly differentiated surface characteristic of Mars to the highly differentiated (actually three-layered) structure of the Earth, the frequency curve characterizing the surface topography should undergo several radical changes. Periodically appearing and disappearing, the intermediate "basalt" level (which is only poorly developed on Mars) should have a progressively greater area on the curve.

We shall now say a few words about Venus, whose surface is not accessible to direct observation. The size of this planet, which measures 12.4 thousand km together with the atmosphere, indicates, in accordance with the previous discussion, that it is well advanced on its evolutionary path. The vigorous generation of the atmosphere on its surface also points to intense processes of relief formation. The composition of the Venusian atmosphere — enormous amounts of nitrogen, CO_2, oxygen, and water vapor — can only be a consequence of considerable internal activity. The large quantities of nitrogen liberated from the interior are transformed to C_7^{14} and O_8^{16} and enormous amounts of water vapor as a result of certain known nuclear reactions, under the influence of cosmic factors /2/.

The rapid growth of Venus should have broken its granitic crust (there is no question but that granite is the main constituent of the Venusian shell) resulting in the formation of deep, apparently as yet rudimentary, oceanic

basins. The frequency curve of Venusian heights and depths should therefore have two maxima. To sum up, certain theoretical premises /2/ enable us to develop a fairly reliable characterization of the relief of some planets of the solar system.

REFERENCES

Publications in Russian

1. NEIMAN, V. B. Geofizicheskii smysl gipsograficheskoi krivoi (Geophysical Meaning of the Hypsographic Curve). — Byulleten' MOIP, geologicheskii otdel, No. 6. 1954.
2. NEIMAN, V. B. Rasshiryayushchayasya Zemlya (The Expanding Earth). — — Geografgiz. 1962.
3. NEIMAN, V. B. O prirode osnovnykh lunnykh obrazovanii (On the Nature of Principal Lunar Formations). — Byulleten' Vsesoyuznogo astronomo-geodesicheskogo obshchestva, No. 30. 1962.
4. SHEIMANN, Yu. M. Platformy, skladchatye poyasy i razvitie struktury Zemli (Platforms, Folded Belts, and the Development of the Earth's Structure). — Magadan, VNII, No. 1. 1959.

Publications in Other Languages

5. FRANBERT, W. Lehrbuch der kosmischen Physik. Leipzig und Berlin. 1911.
6. FRANZ, G. Höhenschichten — Karte des Mondes. — Astronomische Beobachtungen d. Königsberger Sternwarte, 38 (75). 1899.
7. PENK, A. Morphologie der Erdoberfläche. — Bd. I, II. Stuttgart. 1894.
8. SCHRUTKE-RACHTENSTAMM, G. and J. HOPMANN. Die Figur des Mondes. — Abteilung, II. Sitzungsbericht, Bd. 167, H. 8–10. Wien. 1958.

PART FOUR
SOLAR ACTIVITY AND THE EARTH

V. V. Arsent'ev

GIANT SOLAR FLARES IN 1961

Solar radiation is characterized by high stability. A drop of its intensity to one half its present value would reduce the temperature on the Earth much below the freezing point. All water bodies would turn to ice, and no life would be possible. A fourfold increase in the flux of solar heat and light would bring the oceans to the boiling point, and similarly destroy all life. However, geological findings show that life has existed on our planet for at least a billion years. Hence we come to the conclusion that during this entire period the flux of solar energy reaching the Earth did not change, or varied but insignificantly. Therefore the radiation of the Sun as a whole also remained constant or fairly constant.

Theoretical calculations show, in fact, that the solar radiation increased during this time by some 10%. This variation, of course, is not highly significant. It is moreover possible that the Earth's atmosphere, which greatly changed during the evolution of our planet, offset to a certain extent the increase in the radiation of the day luminary and that the flux of solar radiation reaching the surface of the Earth increased by less than one tenth.

Not all stars are as calm as the Sun. The radiation flux of variable stars changes considerably. It sharply increases when novae flare up; when supernovae erupt, their brightness increases in a very short time many millions of times.

Although the luminosity of the Sun remains fairly constant, its surface is by no means immutable. We have known of the appearance of dark spots on the Sun for a long time. In far antiquity our forefathers saw them with the naked eye, and the first written record of a sunspot observation dates back to 188 A.D. Observations of sunspots are recorded in ancient Chinese chronicles. One of the Russian annals mentions that in 1371 "spots dark like nails" were visible on the Sun. An analysis of perennial observations of the Sun carried out at the end of the first half of the last century showed that the number of sunspots on the solar surface varies from year to year, reaching a high approximately every 11 years. Distinct cyclic repetition was observed on the Sun. Most of these changes are quite rapid and some are violent.

A solar activity maximum was last observed in 1958, when a multitude of variable phenomena were recorded on the Sun. At about that time, in 1957-1958, the solar research in many countries followed a single program set for the International Geophysical Year (IGY). The day luminary was almost always in the field of vision of observers in one or several observatories, i.e., almost continuous observations were made. The solar activity will reach a low, as the astronomers expect, in 1963-1964. Solar research in almost all the countries of the world will then again follow the

program of the International Year of the Quiet Sun. According to some researchers, the minimum of solar activity will occur somewhat later, in the first quarter of 1965.

Having reached a maximum, the solar activity mostly decreases rapidly and no outstanding solar phenomena are observed. However, the 1958 peak was exceptionally high, the most powerful of all recorded until now. Therefore, apparently, even by the middle of 1961 the Sun has not quieted down by any means.

Sunspots, which are relatively cold regions of the solar surface, have been known for so long because they are so easy to detect. While the temperature of the visible surface, the photosphere, reaches almost 6 thousand degrees, the temperature in a sunspot is a mere 4.5 thousand degrees. Although the sunspots in themselves are fairly bright, they seem dark in comparison with the intensely luminous surrounding surface. A sunspot can be regarded as some sort of a recess in the photosphere. The depth of this recess may reach several thousands of kilometers, but apparently no more than 10,000 km.

A large group of sunspots was discovered on 9 July 1961 at the Mountain Astronomical Station near Kislovodsk. Many of these spots measured up to 40,000 km in diameter, i.e., more than thrice the diameter of our planet. Some spots may be up to 200,000 km long, i.e., their diameters are equal to half the distance to the Moon. According to observations of Soviet astronomers, the largest number of sunspots during July 1961 was recorded on the 19th. The smallest number was observed on 30 July. The Wolf number, which characterizes the number of individual sunspots and spot groups*, was 144 for 19 July and 32 for 30 July.

Of considerable interest is the large group of sunspots observed between 9 and 20 July. On 14 July it passed through the central meridian of the Sun. On 9 July the group comprised 16 spots, their number increasing to 41 by 15 July; by 20 July only 5 spots remained. The surface area occupied by this spot group increased rapidly. On 12 July it reached a high of 4.7 billion km^2, i.e., more than 9 times as great as the entire surface of our planet. The largest spot of the group then had an area of 3.9 billion km^2. But this enormous sunspot was still far from breaking the record: on 7 April 1947, near a solar activity maximum, astronomers observed a sunspot with an area of over 180 billion km^2.

Prominences are more difficult to detect than sunspots, but they are one of the most interesting and spectacular kinds of solar phenomena. These unusual "fountains" of incandescent gas rise to a height of up to a million kilometers above the surface of the Sun, moving in some cases with a velocity of 600 km/sec. One of these giant prominences was observed on 23 July 1961 by V.G. Banin and V.F. Chistyakov, at the Far-East Astronomical Station.

Comparatively recently, little over 100 years ago, were discovered the chromospheric flares—truly remarkable and most powerful of the solar phenomena. These mostly originate in the middle layer of the solar atmosphere, the chromosphere, whence their name. Flares generally appear near spot groups and are related to them.

The brightest chromospheric flares can be seen even in daylight. Carrington and Hodgson, on 1 September 1859, were the first observers.

* The Wolf number $W = k^2(10g+f)$, where g is the number of spot groups, f is the number of individual spots, and k is a coefficient depending on the instrument and the observer; introduction of this rather subjective coefficient enables different observations to be compared.

Ordinarily, however, flares are not much brighter than the surrounding regions of the solar surface, so that as a rule they are detectable only with spectroscopic apparatus. The chromospheric flares appear particularly bright in lines of the spectrum emitted by hydrogen atoms. In this light the flares are one order of magnitude brighter than the surrounding parts of the Sun.

The summer of 1961 was rich in chromospheric flares. In July, over twenty flares were recorded at the Crimean Astrophysical Observatory of the Academy of Sciences of the USSR alone. Each flare generally persists for no more than half an hour. The flare of 18 July, however, was observed for 1 hour 22 minutes. Its area was over 7.5 billion km^2, i.e., 15 times as great as the entire surface area of the Earth.

The chromospheric flares emit most of their energy in the ultraviolet and the X-ray regions of the spectrum. These emissions disturb the ionospheric layers of the Earth's atmosphere, which act as a kind of mirror for the reflection of short radiowaves. These disturbances result in the partial breakdown of short-wave radio communication. Since X-ray and ultraviolet radiations propagate with the velocity of light, the ionospheric disturbances produced by these emissions set in immediately after the flare.

Electrically charged particles, corpuscules, are also emitted from the flare focus, their velocities reaching 1-2 thousand km/sec. After a little over 24 hours they hit the Earth. When the Earth meets the stream of solar corpuscules, complex electromagnetic phenomena occur. Polar aurorae are observed. Prolonged breakdown of short-wave radio communication takes place, and magnetic storms arise, making it impossible to use a compass.

As they pass through the solar corona, the corpuscular streams make the charged coronal particles (electrons) oscillate. Radiowaves are emitted owing to these oscillations. This may enhance the radioemission of the Sun a thousandfold, and during very powerful flares even a millionfold. In the middle of July 1961 the solar radioemission was intensified by a factor of 50 on meter waves.

Flares sometimes give rise to streams of cosmic rays too. Hitting the Earth's atmosphere, cosmic rays destroy molecules and atoms of gases and thus disappear themselves. Showers of fragments of broken atomic nuclei reach the surface of the Earth from the atmosphere. Particularly intense cosmic-ray showers were observed following the chromospheric flare of 23 February 1956. After the chromospheric flare of 12 September 1959, Soviet researchers observed an increase by a factor of 12 in the count of heavy nuclei reaching a counter.

Another phenomenon linked with chromospheric flares was discovered a few years ago. After the prodigious flare of 23 February 1956, French astronomers headed by Prof. A. Danjon, director of the Paris Observatory, recorded a certain slow-down of the Earth's rotation. While before the flare the Earth was in the middle of its seasonal acceleration, which started on 27 September and shortened the period of rotation by 7.2 microseconds per day, after the flare the period of rotation started increasing by 2.5 microseconds per day. According to Danjon, the deceleration of the Earth's rotation occurred a few hours after the flare.

The discovery was so unexpected that at first many astronomers questioned the actuality of the phenomenon observed. Only much later, when artificial satellites and space rockets led to the discovery of radiation

belts around the Earth was the deceleration of terrestrial rotation attributed to the interaction of charged particles of these belts with the corpuscules emitted by the Sun.

Some observers, however, expressed their doubts of the validity of the results obtained by Danjon. The question of the deceleration of the rotation of our planet as a result of flare effects therefore still remains open.

It is remarkable that in July 1961, after the appearance of the magnificent flares, the American artificial satellite Echo-I, according to the data of French astronomers, accelerated its revolution around the Earth.

The nature of chromospheric flares has not yet been fully studied. These flares are enormous explosions, immeasurably more powerful than A- and H-bomb explosions. They are set up by interactions of electric and magnetic forces. In all probability these are unusual compression explosions produced by the solar magnetic field.

The processes occurring on the face of the Sun have a significant influence on many terrestrial phenomena and even on the behavior of our planet as a whole. As we progress in our understanding of the rules governing solar activity, we shall improve our ability to predict its undesirable consequences, e.g., magnetic storms and radio breakdown. The enormous achievements of science in the study of the cosmos make us confident that the secret of the origin of solar activity will be disclosed in the near future.

S.I. Isaev

ON THE EXISTENCE OF A REGION OF ENHANCED AURORAL ACTIVITY TO THE SOUTH OF THE ZONE OF MAXIMUM AURORAL FREQUENCY

During the International Geophysical Year visual observations of polar aurorae were carried out by a large network of meteorological stations in the Soviet Union. According to the international agreement, the data had to be reduced to tables of the southern limit of aurorae seen near the zenith. The southern limit of visibility of polar aurorae is one of the most objective characteristics of auroral activity.

The statistical treatment of the initial material for the period from September 1957 to December 1958 presented to us by N.V. Pushkov (IZMIRAN) showed that the behavior of the southern limit of polar aurorae (aurora borealis) near the zenith has the following remarkable property:

1. In the first half of the day (00-12 hrs universal time) the mean position of the southern limit of zenith auroral visibility has a distinct stable maximum at geomagnetic latitude $\varphi = 60-62°$.

2. In the second half of the day (12-24 hrs universal time) the mean position of the southern limit of zenith auroral visibility, besides the maximum at $\varphi = 60-62°$, develops a second distinct maximum at $\varphi = 57-58°$.

This pronounced regularity is illustrated in Figure 1, which gives the mean distribution of the number of occurrences of southernmost zenith aurorae as a function of the geomagnetic latitude in the first and the second half of the day for separate geomagnetic longitudinal belts. Figure 2 gives the results of an analysis of the behavior of these maxima for various geomagnetic activities (K-index)*. The figures lead to the following conclusions:

1. Aurorae clearly prevail in the second half of the day; their number increases with increasing K-index.

2. In the first half of the day (00-12 hrs U.T.) the mean position of the southern limit of auroral visibility shifts southward by a mere 2° with increasing geomagnetic activity; with $K = 1$ the maximum is located at $\varphi = 62°$, and with $K > 5$ at $\varphi = 60°$.

3. In the second half of the day (12-24 hrs U.T.) the position of the maximum is more stable; it is located on the average 1° to the south of the maximum observed in the first half of the day. As the K-index increases, the maximum almost does not change its latitude.

4. Although retaining its mean position despite variation of the K-index, the second maximum (at $\varphi = 57°$) sharply changes in magnitude. A weak maximum appears at $K = 2$; at $K = 3$ it is already well pronounced; at $K = 4$ the maximum is more than twice as large as the first maximum (at $\varphi = 60-62°$).

* K-index according to the data of Soviet stations was taken from "Kosmicheskie dannye" published by IZMIRAN. To ensure higher statistical reliability the data for longitudinal belts 145-190° and 190-235° have been combined.

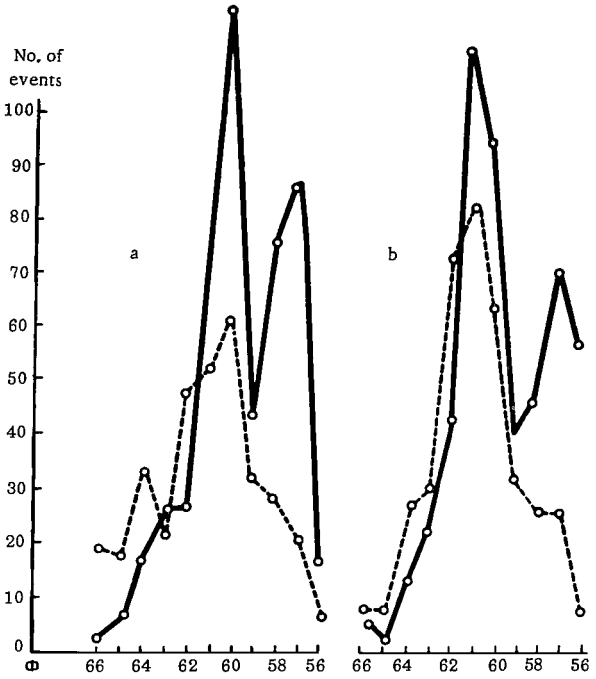


FIGURE 1. The number of occurrence of southernmost zenith aurorae as a function of the geomagnetic latitude:

a—for the 145-190° geomagnetic longitudinal belt; b—for the 190-235° geomagnetic longitudinal belt; dashed curve—the first half of the day (00-12 hrs universal time); solid curve—the second half of the day (12-24 hrs universal time).

The presence of a distinct maximum of southern zenith auroral occurrence at $\varphi = 60-62°$, the appearance of a second sharp maximum at $\varphi = 57°$ during geomagnetic disturbances, and the variation of the height of the second maximum with geomagnetic activity are all consistent with our previous conclusion concerning the possible existence of an additional zone of enhanced auroral activity in middle latitudes during strong geomagnetic disturbances /1/. Now we can definitely assert that during large geomagnetic disturbances, in years of solar-activity maximum, an additional stable auroral zone appears in middle latitudes, at least in the 145-235° geomagnetic longitudinal belt, to the south of the principal zone ($\varphi = 68°$), which at night splits into two maxima.

The existence of a zone of enhanced auroral activity at $\varphi = 52-62°$ corresponds to the region at which radiation from the outer radiation belt should arrive along the geomagnetic force lines. The outer zone, as we know, is limited by force lines intersecting the surface of the Earth at geomagnetic latitudes 55 and 65°. Observations of the radiation belts made by Arnoldy, Hoffman, and Winkler /7/, with the aid of the artificial satellite Explorer-IV during August-September 1959, showed that during the geomagnetic storm of 16-17 August 1959 the intensity of 65 Å radiation in the outer belt decreased and the spectrum of the remaining radiation grew harder.

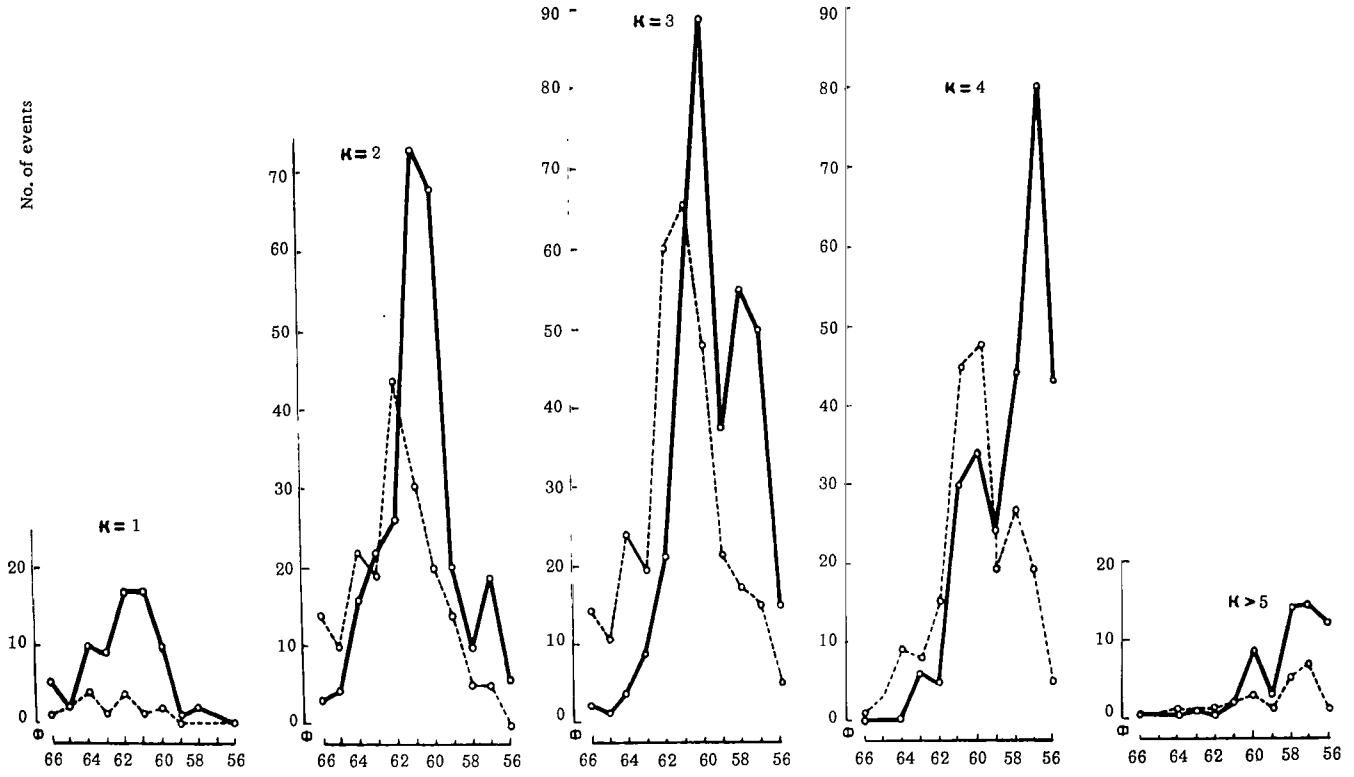


FIGURE 2. The number of occurrence of southernmost zenith aurorae as a function of the geomagnetic latitude in the first (dashed line) and the second (solid curve) halves of the day for various values of the K-index.

If radiation escapes from the outer belt along the geomagnetic force lines, it should reach the Earth's atmosphere at $\varphi = 52-62°$, creating X-rays there. It is assumed that this radiation gives rise to X-rays of a special kind of polar aurora observed to the south of the main auroral zone and accompanied by magnetic disturbances with K_7-K_9. Indeed, on 16-17 August a bright polar aurora of ray structure was observed at a latitude of 57°.

Our conclusions statistically confirm the possibility of the existence of an enhanced auroral zone in middle latitudes during geomagnetic storms; the results of studies of these aurorae can be successfully used to elucidate the behavior of the outer radiation belt, which is related to the solar corpuscular radiation /2, 3, 4/.

Barbier and Glaume /8/ observed in winter in Tamanrasset (22°47'N) arcs which moved from the north to the south toward the end of the night. In these arcs the 6300 Å radiation reached an intensity of 557 R and the 5577 Å radiation had an intensity of ~ 500 R. At the same time in Haute Provence (43°56'N) the intensity of 6300 Å radiation was ~ 200 R. In summer the intensity of 6300 settled to the value common for night-sky glow. The authors maintain that the arcs in Tamanrasset were due to the existence, in low latitudes, of auroral zones related to electrons of the inner radiation belt. The mechanism of polar aurorae in middle and low latitudes during geomagnetic storms can thus be of the same origin, being directly connected with radiation belts of the Earth.

The high-latitude aurorae in the principal zone ($\varphi = 68°$), where they are observed almost incessantly, apparently occur as a direct consequence of solar corpuscules. Allowing for the geometrical form of the radiation belts, we see that the corpuscules may reach this part of the Earth's atmosphere bypassing the intermediate pool of electrons enclosed in the outer radiation belt, from which electrons are "shaken out" only during instability spells. Therefore in high latitudes, where the corpuscules are not trapped by the radiation belts, the interaction of the corpuscular streams with the geomagnetic field may still be according to the "Störmer" mechanism.

The principal high-latitude auroral zone at $\varphi = 68°$ retains its position during both magnetically quiet days and any magnetic disturbances. During polar geomagnetic disturbances the number of polar aurorae in the principal zone sharply increases. During polar geomagnetic disturbances in the principal zone [the number of aurorae] virtually does not increase — only their duration and intensity increase. At $\varphi = 64°$, however, an additional active belt arises in these periods, adjoining the principal auroral zone. The additional belt is apparently responsible for the splitting of the principal auroral zone during disturbances, observed by some authors. The splitting is difficult to detect, since the additional active belt closely adjoins the principal zone and is observed only as an overall broadening of the principal auroral zone by 3-4° to the south /1/.

Auroral activity in middle latitudes during strong geomagnetic disturbances is apparently not due to a placement of the principal auroral zone to more southern latitudes, but rather to the appearance of a new additional zone in the middle (and possibly of another active zone in low) latitudes. It is remarkable that the middle-latitude zone also shifts somewhat to the south and splits, the splitting being more pronounced than in the high-latitude zone.

These zones (the high-latitude principal zone, the middle-latitude and, possibly, the low-latitude zones) all overlap. Because of the mutual overlap of the zones of enhanced auroral activity there seems to be an overall

"creep" of aurorae to the south during geomagnetic storms, down to the equatorial latitudes, and the "fine" structure of the true latitude distribution of the aurorae is obliterated.

The discovery of a zone of enhanced auroral frequency and intensity in the circumpolar region ($\varphi = 78-80°$) /1, 5, 6/ and the complex latitude distribution of the auroral zones to the south of the principal Fritz zone ($\varphi = 68°$) point to the need for further thorough study of the geographical distribution of aurorae and elucidation of the mechanism of their southward migration during geomagnetic storms. Detailed observations of polar aurorae in middle and low latitudes are now of particular interest.

REFERENCES

1. ISAEV, S. I. Geograficheskoe raspredelenie polyarnykh siyanii i otnoshenie etogo voprosa k geomagnitnym i ionosfernym vozmushcheniyam (Geographic Distribution of Polar Aurorae and the Relation of This Question to Geomagnetic and Ionospheric Disturbances). — Thesis. Lenin Library, Moskva. 1954.
2. VAN ALLEN, J. A. Geomagnetic-trapped Corpuscular Radiation. — In: Trudy Mezhdunarodnoi konferentsii po kosmicheskim luchyam. Radiatsionnye poyas Zemli, Vol. III, Izdatel'stvo AN SSSR. 1960.
3. VERNOV, S. N. and A. E. CHUDAKOV. Issledovanie izluchenii v kosmicheskom prostrantsve (Study of Radiations in Cosmic Space). — In: Trudy Mezhdunarodnoi konferentsii po kosmicheskim lucham. Radiatsionnyi poyas Zemli. Vol. III, pp. 17–32. Izdatel'stvo AN SSSR. 1960.
4. ZINGER, S. F. Priroda i proiskhozhdenie radiatsionnykh poyasov Zemli i ikh svyaz' s plotnost'yu verkhnikh sloev atmosfery i geofizicheskie effekty (The Nature and Origin of Radiation Belts of the Earth and Their Relation with Density of Upper Atmospheric Layers, and Geophysical Effects). — In: Trudy Mezhdunarodnoi konferentsii po komicheskim lucham. Radiatsionnyi poyas Zemli, Vol. III, pp. 59–68. Izdatel'stvo AN SSSR. 1961.
5. NIKOL'SKII, A. P. K voprosu o geograficheskom raspredelenii polyarnykh siyanii v Arktike (On Geographic Distribution of Polar Aurorae in the Arctic). — In: Issledovanie polyarnykh siyanii, No. 4, pp. 14–10. Izdatel'stvo AN SSSR. 1960.
6. ALFVEN, H. — Tellus, **7**(1) : 1955.
7. ARNOLDY, R. L., R. A. HOFFMAN, and J. R. WINKLER. Observations of the Van Allen Radiation Regions during August and September 1959, Part I. — J. Geophys. Res., **65**(5), 1361—1376. 1960.
8. BARBIER, D. and J. GLAUME, Sur l'existence possible de nouvelles zones aurorales. — C. R. Acad. Sci., Paris, **250**(11), 2043–2044. 1960.

A. L. Chizhevskii

ONE ASPECT OF THE SPECIFIC BIOACTIVE OR Z-RADIATION OF THE SUN*

A thorough study of the effects on organisms of certain powerful environmental factors should now be conducted. For this, all necessary forces and resources of our scientific wealth should be converged because, as will be shown, these might become one of the most acute problems in the complex practice of therapeutics and prophylaxis.

Until thirty or forty years ago, biologists used the term "outer environment" mainly to designate the meteorological and geophysical factors that may in some way act on the organism and elicit certain reactions. I. P. Pavlov included in the complex of outer environmental factors a large number of stimuli surrounding man and acting on his senses and central nervous system. Modern science has greatly expanded the concept of outer environment to include interplanetary space, from which electromagnetic waves of various wavelengths and streams of electrically charged particles reach us. Thus, the term outer environment implies the entire surrounding world with its great diversity of stimuli.

As a result of the remarkable progress made in the fields of physics and biological sciences we have come close to solving several cardinal problems concerning the effects of radiations on the human organism and, particularly, of certain specific active radiations of the central body of our planetary system. Although the Sun is about 149 million kilometers from the Earth, it is "a stone's throw away," since its diameter is approximately 1.39 million kilometers, and hence the distance between the Sun and Earth is only about 107 Sun diameters.

The most easily observed features on the Sun"s surface are the sunspots. They had been clearly described at the beginning of the 17th century. Since the mid-19th century they have become an "index" of the intensity of solar activity, and the subject of thorough heliophysical studies. A voluminous body of physical data is now available in the literature dealing with the nature of sun spots and of accompanying phenomena such as faculae, filaments, flares, bursts, prominences, etc.

Sunspots represent areas of the photosphere associated with a powerful magnetic field. They are caused by convection in the solar nucleus transmitted by magnetohydrodynamic waves to its surface as a result of

* ["Z-radiation" is Chizhevskii's designation for a certain type of solar radiation emitted from the deep layers of the Sun.]

thermonuclear reactions. Sunspot groups extend over vast areas; in 1947 a group was found to occupy an area of 10 billion km^2. These solar formations could instantaneously swallow dozens of terrestrial globes. No less striking are the prominences (which sometimes rise to hundreds of thousands of kilometers above the photosphere at velocities of up to 700 km/sec and partially disappear in interplanetary space), as well as the exceptionally bright, dazzling transient flares which suddenly appear and which emit radiations of extreme intensity in the shortwave ultraviolet region. Heliophysical studies have established a striking regularity in the occurrence of these tremendous solar phenomena. The basic cycle of solar activity takes approximately 11 years, with certain fluctuations in both directions. This infers that the number and size of the spots visible on the Sun's surface are comparatively small for a period of two or three years, followed by a steady increase in the number and dimensions of the spots and their groups, until they finally reach a maximum size and frequency in the period of maximum solar activity. The synodic period of the rotation of the Sun is 27 days. Consequently a sunspot or any disturbed area is visible for a period of 13.5 days, whereupon it passes to the other side of the Sun for the same period. It takes about a week for a sunspot to enter the plane of the central solar meridian from the solar limb.

When sunspots, bursts, prominences, chromospheric flares, etc. pass through the plane of the central solar meridian, they generate a series of extreme perturbations in the Earth's crust and atmosphere such as magnetic storms, polar auroras, fluctuations in the gradient of the electric potential in the atmosphere, interferences with wire and wireless communication, and many other anomalies in the Earth's atmosphere, hydrosphere, biosphere, and lithosphere. The functional correlation of many biological and solar phenomena can be regarded as firmly established. The extent of influence of this bond and the correlation coefficients of the given phenomena increase progressively with the accumulation and accuracy of heliophysical, geophysical, and biological observations. In addition to the basic 11-year solar activity cycle, 27-day perturbation periods were observed, which are related to the Sun's rotation around its axis, i.e., to the shifting of the active sites on the Sun with respect to the Earth. There are also other, less clearly defined cycles /80/.

The active processes on the Sun derive from highly powerful pulse sources of electromagnetic or corpuscular radiation generated by the thermonuclear processes within the Sun. Electromagnetic radiations of the disturbed sites on the Sun are characterized by a wide band. In years of maximum solar disturbance there is a marked increase in the emission of X-ray as well as ultraviolet and infrared radiation. The intensity of ultraviolet radiation from the chromosphere of giant flares is hundreds of thousands and even millions of times greater than the intensity of ultraviolet radiation from the solar surface. Solar radiation in the infrared spectral region was discovered fairly recently. This discovery gave rise to the new science of radioastronomy. Solar radioastronomy comprises the study of radio waves emitted by the active areas of the Sun. These studies are performed with the aid of radiotelescopes, i.e., huge antennas of different shapes which detect solar radio waves of wavelengths ranging from 20 m to a few millimeters. It is now firmly established that the intensity of solar radio emission varies in direct proportion to the size of

the sunspots, and to the power and intensity of the sudden flares, bursts, and explosions on the Sun's surface. At the stage of maximum solar activity the intensity of radio radiation from large spots is occasionally millions of times greater than the radiation level recorded during "quiet" periods. In addition to a "Sun bureau" many countries have also organized a "solar-radio bureau" which forecasts certain terrestrial phenomena from the solar radiowaves.

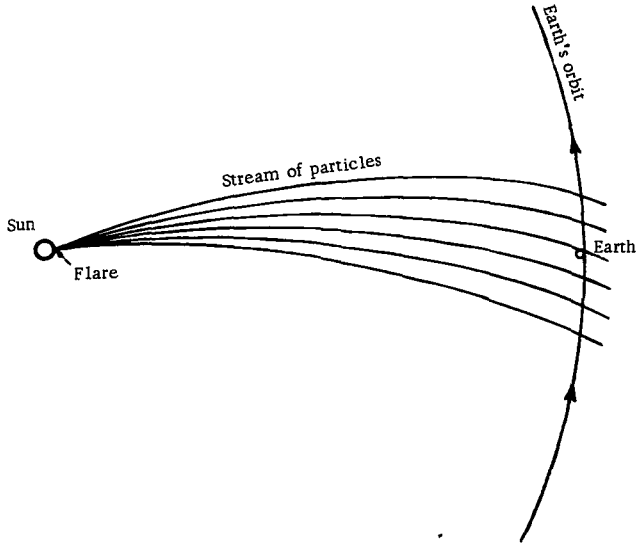


FIGURE 1. Emission of particles by a disturbed area on the Sun's surface. The Earth is bombarded by the particles as it moves along its orbit.

In addition to light, roentgen, ultraviolet, and radio radiations, the Sun also emits into interplanetary space, from its disturbed areas, streams of electrically charged particles of positive or negative polarity with ultrahigh energies. A solar corpuscular stream extending over an area with a cross section of hundreds of thousands of square kilometers travels the distance between the Sun and the Earth in about a day, and bombards the upper layers of our atmosphere. During maximum solar activity these streams suddenly gain an extremely high momentum.

As an example, on 29 March 1960, at 0940 hr Moscow time, a strong chromospheric flare was observed in the region of a group of sunspots. At 1200 hr on 31 March a strong geomagnetic and ionospheric storm set in, accompanied with intense auroras in the middle latitudes. On 1 April shortwave radio communications were disrupted for several hours in the northern, middle, and southern latitudes. Communication between Europe and America, as well as between several European cities, was cut off.

The lower boundaries of the biosphere are not reached by the entire spectrum of solar radiation. The upper ionized layers of the terrestrial atmosphere intercept part of the electromagnetic band of solar radiation.

Waves of up to 20 m partially penetrate these layers and reach the Earth's surface in an attenuated state. The depth of penetration of the solar corpuscular radiation into the terrestrial atmosphere is not yet definitely known. On the basis of numerous theoretical and experimental studies it may be assumed that solar corpuscular streams, while ionizing the upper layers of the terrestrial atmosphere, lose their speed and are deflected by the terrestrial magnetic field and thus, the corpuscular solar radiation does not reach the biosphere. Nevertheless, it is assumed that certain solar corpuscles having the high energy of cosmic rays may reach the Earth's surface. However, it cannot be assumed that all electromagnetic and corpuscular radiations of the Sun are known to modern science.

On the basis of their observations, several prominent scientists of the nineteenth and early twentieth centuries, including Svante Arrhenius, Fridtjof Nansen, and others, not only assumed the possibility of a direct effect of solar storms on certain phenomena in the troposphere, and particularly in the organic world, but actually established a series of correlations. The relationship between the solar activity cycle and phenomena of the organic world was successfully studied in Russia before the revolution, and is now being investigated in the Soviet Union by numerous scientists, including F. M. Shvedov, N. A. Skalovskii, N. M. Kulagin, D. O. Svyatskii, P. Yu. Shmidt, A. P. Moiseev, G. A. Ivashentsov, V. B. Shostakovich, S. T. Vel'khover, A. A. Sadov, G. I. Pokrovskii, E. A. Slutskii, N. S. Shcherbinovskii, N. A. Shul'ts, N. V. Romenskii, and others. The scientific value of such investigations was described by Prof. M. S. Eigenson in his article "Recent Trend in Space Biology,"* and in his "Essays on the Physicogeographical Manifestations of Solar Activities."** This field of science is gradually achieving its legitimate place among the natural sciences. In countries outside the USSR this science has been enriched by numerous investigations in "heliobiology" (Oenström, Hallend-Hansen, Lemström, Hahn, Fritz, Shaw, Faure, Hütington, Douglass, Morill, Memory, Ballou, win, Amman, Smitt, Kritzinger, Morrill, Düll, Takata, Murazugi, Budai, Denier, L. Schluck, Reinhold, Edward Dewey, Helmut Berg, and others).

In 1915 the author of this article /1/ energetically undertook, for the first time in the history of science, to make a break-through in this field, selecting the following two research trends which seemed to be the most promising: studies of changes in the functional state of the human nervous system under the effect of solar factors /1, 4, 6, 14, 15, 23, 25–28, 30, 31, 40, etc./, and studies of the world statistics of epidemic diseases, where the large numbers could facilitate detection of the reflected effect of solar disturbances. Indeed, a certain parallelism was soon established between the incidence of most pandemics and epidemics in the course of the 16th to 19th centuries (cholera, grippe, plague, diphtheria, relapsing fever, and cerebrospinal meningitis) and the solar activity cycle /5, 6, 10, 13, 16, 19, 41, 51, 57, 59, 60–64, 70, 72–78, 80/. The correlation coefficient between the solar and the epidemiological curves often reaches

* Novyi put' kosmicheskoi biologii.— Vestnik Akademii Nauk Kazakhskoi SSR, No. 9, p. 28, Alma-Ata. 1953.

** Ocherki fiziko-geograficheskikh proyavlenii solnechnoi aktivnosti, Lvov. 1957.

values of 0.8–0.9 (Figures 2–7). Although incidence of epidemic diseases is closely linked with socioeconomic conditions and numerous other factors, such as sanitation facilities, housing, nutrition, war, famine, unemployment, etc., these conclusions have been confirmed by thousands of studies and are unquestionably accurate.

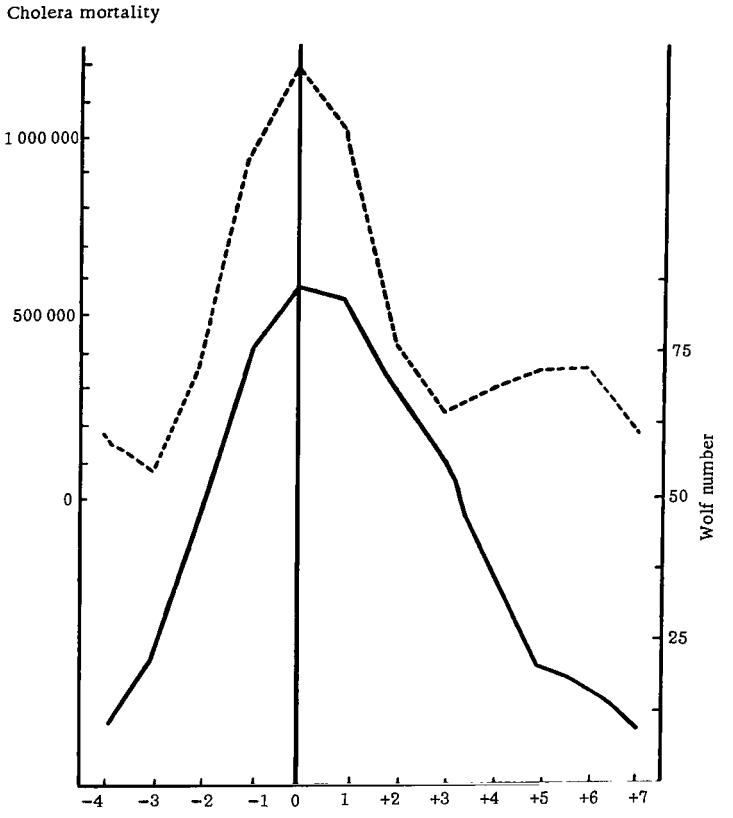


FIGURE 2. Upper curve: cholera in Russia and the USSR during the period 1823–1923; lower curve: solar activity over the same period. Result of superimposing both curves on the axis of maximum solar activity. The zero abscissa represents the year of maximum solar activity; the negative and positive abscissas respectively represent the years preceding and following the maximum.

As could be expected, our findings provoked controversial views among Soviet epidemiologists and microbiologists. In this connection, a proponent of this work, the prominent Soviet doctor G. A. Ivashentsov wrote in 1931: "While technicians build rockets for interplanetary travel, physicians turn away even from phenomena that can be studied here on this planet." Continuing, and referring to the grippe, he wrote: "Studies of the grippe should release this problem from its present deadlock. In attempting to

clarify the effect of factors already known (such as infection and social conditions) epidemiologists should collaborate in their work with meteorologists and astronomers. In addition to the prevailing inertia in scientific medical thought, the passive attitude toward research of the practical significance of complex cosmic phenomena is based on the false concept of our helplessness in controlling their effects on us... However, the dark ages of superstitions, the slavish hopelessness that regards epidemics as a 'punishment from Heaven,' have vanished forever. Several epidemic diseases, closely linked with social conditions, have been eradicated under the socialist government; this urgent problem was clearly understood and successfully resolved. Its solution provides new possibilities for elucidating and solving the following problems: utilization of the beneficial cosmic phenomena and neutralization of the injurious ones; and research of those which have not yet been studied or are regarded as incomprehensible or insurmountable. There is no doubt that proceeding along this path we shall solve several 'hopeless' problems in medicine, and particularly in epidemiology."*

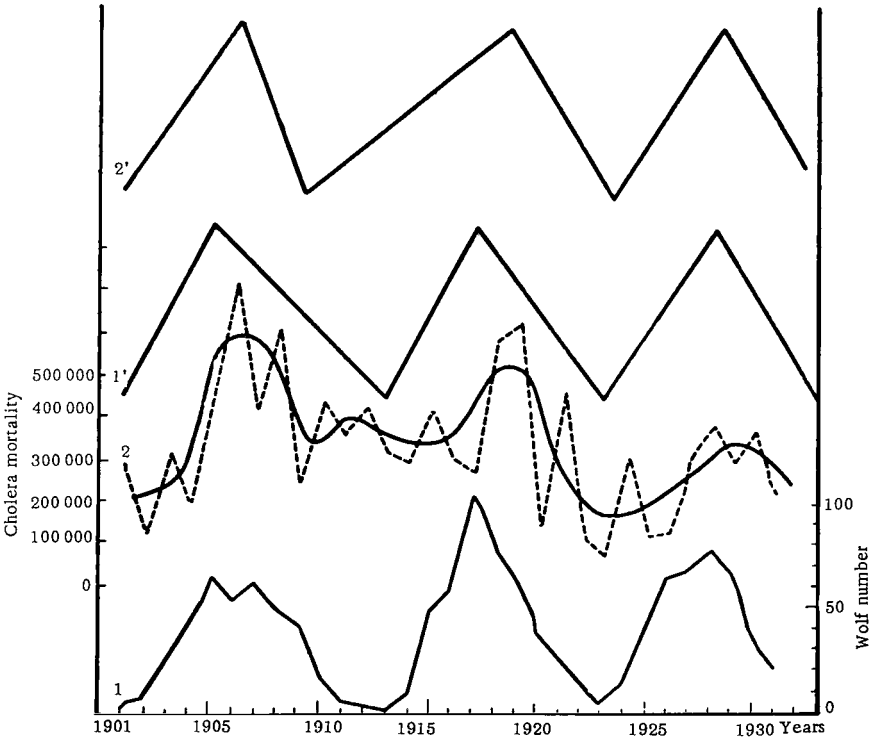


FIGURE 3. Cholera mortality in British India and solar activity from 1901 to 1931. Curves: 1–Wolf number; 2–dynamics of cholera; 1' and 2'–schematic curves showing maxima and minima of the curves 1 and 2 respectively.

* Vrachebnaya Gazeta, No.8, Leningrad. 1931.

The afore-mentioned correlation between epidemics and solar activity has been gradually obscured by the progress in medical knowledge made toward the end of the last century, and reflected by the introduction of vaccinations and various preventive measures, especially social improvements. Many agents of epidemics and pandemics which formerly took hundreds of thousands of human lives have been almost eradicated, with only infrequent outbreaks in their ancient foci. Consequently, epidemiological studies are only of historical and theoretical value; they demonstrate the tremendous role of social reforms and of prevailing medical measures in the control of public health. Therefore, one must agree with the famous microbiologist, Academician S. N. Winogradsky, who mentioned in a letter to the author that, at present, cosmic agents can be ignored with respect to the onset and spread of epidemics, their role being negligible in comparison with that of biological agents. In a letter of 14 November 1935, Winogradsky wrote: "Whenever the etiology is well known, the foci of infection can be suppressed and catastrophic epidemics prevented irrespective of solar activity." Summaries of the author's extensive research in this field have been published in two main monographs: in Moscow, in 1930 /19/, and in Paris, in 1938 /80/. However, in connection with several epidemic diseases (grippe, cerebrospinal meningitis, poliomyelitis, etc.) the effect of the solar factor still requires fundamental study. As grippe pandemics and certain other epidemics continue their periodic attacks on man, the opinion of Academician Winogradsky should be revised.

Periodic outbreaks of cholera epidemics are still being reported from certain countries in southern Asia. Epidemics of poliomyelitis are known to occur in the USA, France, and other countries. Therefore, an accurate prediction of outbreaks of several epidemic diseases is still highly desirable. Helioepidemiological studies are, for certain countries, an urgent medical necessity.

The question arises whether man or the bacterial cell conditions the coordinated development of solar phenomena and epidemics on Earth. Referring to our work, Prof. Dubos /89/ assumed that the cellular growth and metabolic activity of several bacteria are affected by certain specific radiations which, in turn, depend upon the solar activity cycle.

In 1927 we began microbiological research after studying the spread of many epidemic diseases and of the synchronous variations in solar activity during past centuries, and publishing these data in the years 1924 and 1927–1929 /6, 13–16, 24, 27–29/, edited by Prof. N. A. Semashko (who personally contributed considerably to this work). It was shown that ordinary bacterial flora and certain pathogenic microorganisms react distinctly to specific solar phenomena, and this coincidence could be traced with an accuracy of up to 6 days. A few years later, under the direct influence of our work, the Kazan physician and microbiologist, S. T. Vel'khover, conducted a thorough microbiological study, lasting several years (1934–1942), of the effect of solar flares on the growth and metachromasia of Corynebacteria; he confirmed by exhaustive investigation (over 85,000 observations) the existence of a strict correlation between the specific solar radiation and the physicochemical processes in microorganisms. He also demonstrated that these changes occur simultaneously in different places (in three independent laboratories) /86, 87/.

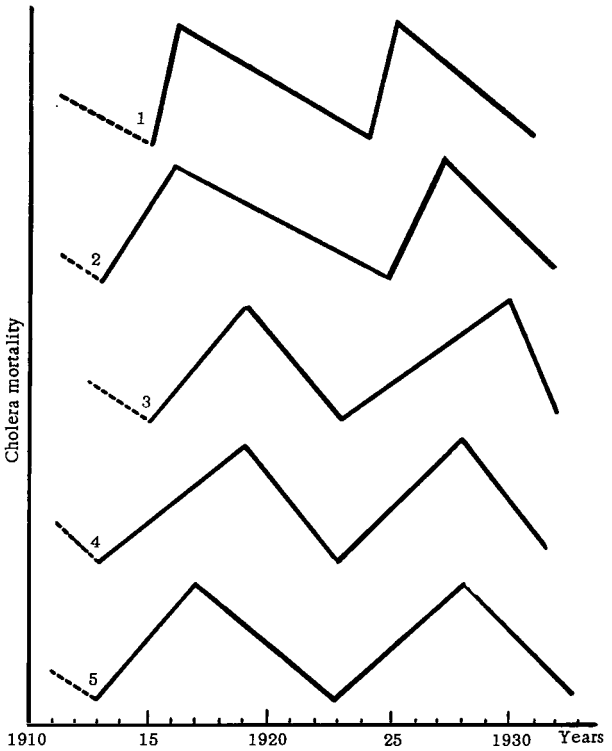


FIGURE 4. Schematic curves of cholera mortality: 1–Japan; 2–Indochina; 3–the Philippines; 4–British India; 5–Wolf number.

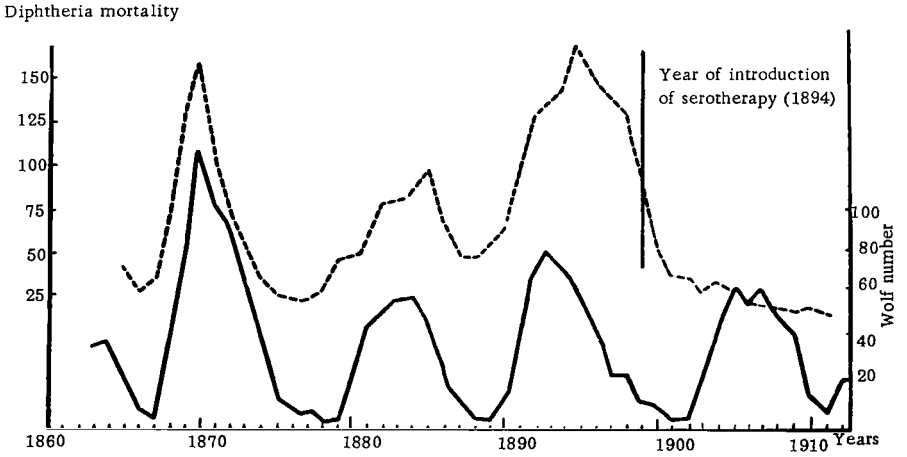


FIGURE 5. Upper curve–diphtheria in Denmark from 1863 to 1911. Lower curve–Wolf number. The diphtheria curve was shifted five years to the right. The vertical line on the upper curve at the right indicates introduction of serotherapy, which cut off the natural course of the epidemics.

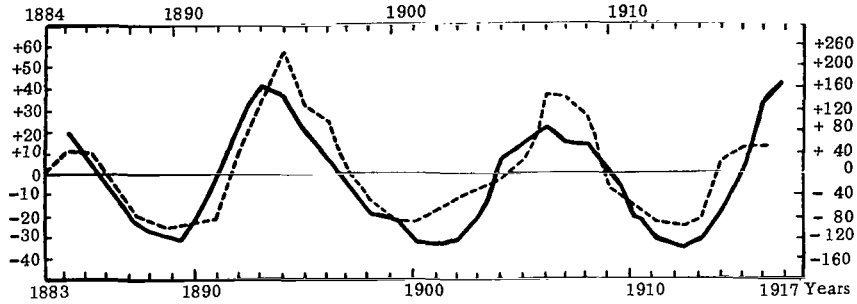


FIGURE 6. Comparative curves of relapsing fever in European Russia from 1883 to 1917 and the Wolf number for the same time period. (The curve for relapsing fever was shifted one year to the left— dashed curve.) The correlation coefficient is + 0.88 ± 0.03.

The vertical scale on the left represents variations of solar activity, and on the right relapsing fever.

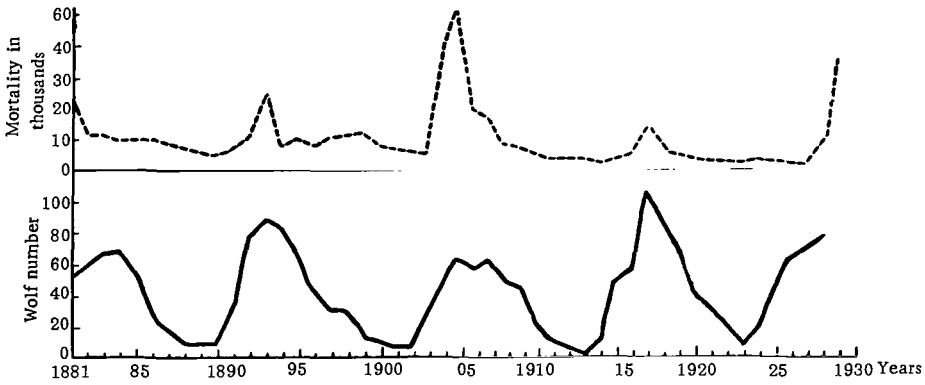


FIGURE 7. Upper curve–epidemics of cerebrospinal meningitis in New York in 1881–1930. Lower curve–Wolf number.

Studies of the microbiological data revealed that changes in the rate of metachromasia in Corynebacteria started several hours, or even days before the solar phenomena were recorded instrumentally by the heliophysicists. We suggested that when this occurred, Corynebacteria were reacting to phenomena developing in the deep layers of the Sun inaccessible to the astrophysical instruments. The volutin of Corynebacteria is seemingly endowed with a high specific sensitivity to this type of radiation, and a method might possibly be elaborated whereby qualitative and quantitative changes in the Sun could be estimated by the chromaticity, or by colorimetric determinations of the volutin granules in Corynebacteria; in other words, heliophysicists must collaborate with microbiologists. Unfortunately our close collaboration with Vel'khover was terminated by his death in 1942. Claims of later authors to priority in this field of science are completely unfounded.

We explained this phenomenon— designated the Chizhevskii-Vel'khover effect— as the metachromatic response of certain microorganisms grown on well-defined media to Z-radiation emitted by the deep layers of the Sun that cannot be recorded astrophysically. This effect was discovered through extensive research which lasted almost 15 years, and required the isolation of a highly sensitive microorganism, a special medium for its cultivation, and the examination of many thousands of preparations. Astrophysicists disagree on the depth at which generation of solar phenomena responsible for Z-radiation occurs. In 1940 the author succeeded in forecasting the appearance of the solar radiations with the aid of live bacteria.

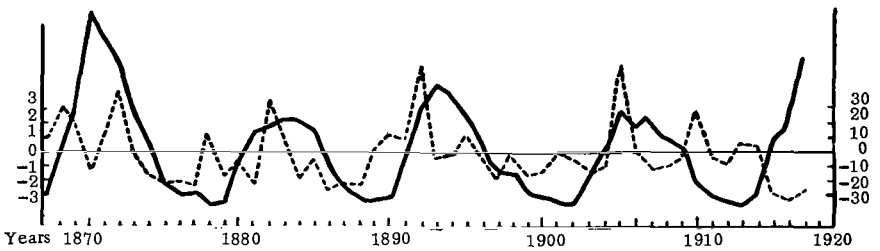


FIGURE 8. Mortality in Russia between 1867 and 1917, and the solar activity cycles. Dashed curve-deviations of mortality from a quadratic parabola. Solid curve-number of sunspots.

The left and right vertical scales respectively represent deviations in mortality and in solar activity.

Not only N. A. Semashko, G. A. Ivashentsov, and S. T. Vel'khover, but many other eminent scientists supported our viewpoint and showed interest in our investigations, rather than regarding them as "fantastic hypotheses." Scientists were already aware at the time that statistical principles were quite as sound as laboratory experiments. Among them were Academicians V. I. Vernadskii, D. K. Zabolotnyi, P. P. Lazarev, K. E. Tsiolkovskii, A. V. Leontovich, V. Ya. Danilevskii, Associate Member of the Academy of Sciences of the USSR Prof. G. D. Belonovskii, Prof. A. V. Reprev, A. A. Sadov, and others, who supported our research verbally or in print. Prof. Sadov repeatedly discussed our studies in the field of epidemiology, and mentioned them in his preface to the well-known book by R. Dujarrique de la Riviere "Ethiology, Epidemiology, and Prevention of Grippe" (1932). These studies were considered most valuable by numerous scientists outside the USSR, among them Prof. L. Tanon (Paris), Dr. D. Budai (Budapest), Prof. J. Renault (Toulon), Prof. S. Sylverst (Paris), Dr. A. Gleitsmann (Berlin), Dr. S. E. P. Brookes (London), Prof. V. Delfino (Buenos Aires), Prof. A. Leprens (Paris), Prof. Laignel-Lavastine (Paris), Prof. V. de Smitt (New York), and many others. Thus, more than 30 years ago our research in the field of epidemiological statistics was already considered by the foremost scientists to be not only interesting but also progressive.

As a result of our statistical investigations we had decided to study the overall mortality, and were able to detect the same remarkable correlation in this field. This subject has a history of its own. In the first decade of this century, some observant physicians noted a phenomenon which

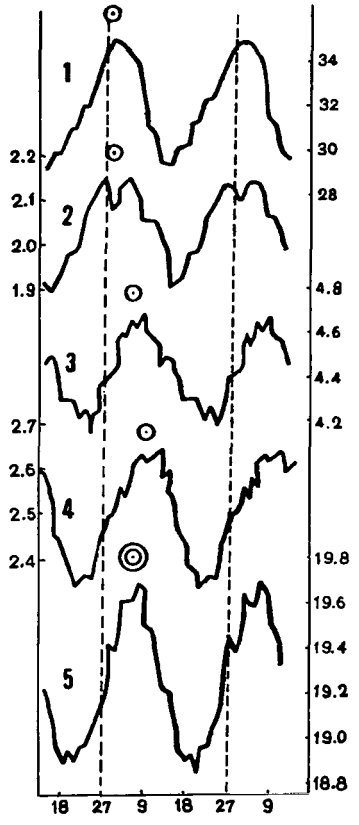


FIGURE 9. 1-Course of magnetic disturbances (world total) for the 27-day period of the Sun's rotation; mean of 68 rotations. 2-Dynamics of mortality caused by diseases of the central and peripheral nervous systems in Copenhagen correlated with the 27-day period of rotation: 3720 cases; mean of 68 rotations for the same period. 3-Dynamics of mortality caused by cardiovascular diseases and senility in Copenhagen, correlated with the 27-day period of the Sun's rotation: 8099 cases; mean of 68 rotations, for the same period. 4-Dynamics of mortality caused by respiratory diseases in Copenhagen correlated with the 27-day period of rotation: 4579 cases; mean of 68 rotations for the same period. 5-Dynamics of mortality due to various causes (with the exception of murders), in Copenhagen, correlated with the 27-day period of rotation: 35,244 cases; mean of 68 rotations for the same period.

The ordinate represents variations in the magnetic field strength of the Earth, and the mortality.

could not be effectively explained for a long time: when patients with acute diseases appeared at the beginning of a physician's office hours, patients with similar complaints could be expected for the rest of the day, and the next two or three days, followed by a certain interval almost free of such patients. Further, it was noted that patients suffering from nervous diseases and affections of the cardiovascular system sustained the most serious attacks at the same time, irrespective of their living conditions. An accurate account of these phenomena revealed that attacks of stenocardia, neuralgic pains, and headaches, for example, attacked a great variety of patients during the same two or three days, and then disappeared simultaneously for a certain time. Statistics showed "sudden deaths" to be strikingly synchronous. Physicians on call at first aid stations in large cities noticed that one sudden death at the beginning of their turn of duty was followed by several additional cases of the same kind within the next day or two. This incidence of diseases, aggravations, and mortality in series has long been a subject of discussion in the scientific medical societies of various countries, and the literature on this problem is fairly voluminous /3, 6, 23, 26-28, 31, etc./.

Attempts at correlating the "pathological series" with meteorological factors (temperature, humidity, atmospheric pressure, wind velocity and direction, thunderstorm discharges, etc.) have failed. Physicians working in medical meteorology have had to conclude, on the basis of extensive statistical data, that distinct correlations are seldom revealed, and do not encompass the great number of coinciding disease and death cases recorded simultaneously over extensive areas in different remote places. Since meteorological conditions differ over vast expanses, they cannot provide a general explanation for the synchronous pattern of the pathology recorded. It was therefore concluded that powerful extraterrestrial factors act in a certain manner upon the entire planetary surface and its biosphere.

By chance, we came closer to an explanation of this enigma. It was noticed that occasionally the functioning of an automatic telephone network was suddenly intermittently, or at times even completely disrupted for several hours, although no breakdowns could be detected in the equipment; in such cases, the network returned to normal without any intervention whatever. The days of disrupted telephone communications were found to coincide regularly with the series of pathological cases, i. e., with the higher frequency of various paroxysms, aggravations, and deaths. The synchronous disturbances in the functioning of electrical equipment and of the human physiological mechanisms revealed an extremely distinct pattern. Magnetic and electric storms on Earth and in the atmosphere play havoc with the electrical networks, and are induced by electromagnetic and corpuscular radiations from the Sun.

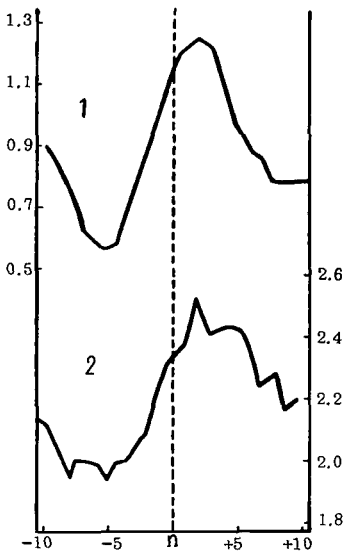


FIGURE 10. 1–Dynamics of magnetic disturbances within 20-day periods; the 10 days preceding and the 10 days following the most violent solar disturbances (n); mean of twenty-two 20-day periods. 2–Dynamics of mortality caused by diseases of the central and peripheral nervous systems in Copenhagen for the same time: 771 cases.

The ordinate represents variations in the magnetic field intensity of the Earth, and the mortality rate.

By processing the wealth of statistical data we were able to demonstrate for the first time that the fluctuations of the overall mortality correlated quite well with the solar activity curve /19, 20/. In years of maximum solar activity the peak of the mortality curve is usually high; whereas in years of minimum solar activity the peak is significantly lower. This may be explained by the influence of the disturbed areas of the Sun passing through the central solar meridian in years of minimum activity, although their number and dimensions as well as their frequency, are very much smaller than in years of maximum activity. As an example, we present the comparative data of mortality in Russia with the curve of solar activity during the years 1867–1917 (Figure 8). The annual mortality curves in different countries were also found to coincide distinctly with the solar activity curves (Chizhevskii, Morrell, Budai, Faure, Mirbach, Vles, and others). In 1925 the author appealed to the Soviet public to help in the collection of data concerning the correlation between cases of sudden death, and geophysical and solar phenomena.* This work was organized by us with the assistance of the Main Geophysical Observatory and the People's Commissariat of Health of the RSFSR.** A two-year work period resulted in the accumulation of a vast amount of data (45,000 cases), which showed 89% of the cases to be synchronous, verifying the desired correlation. In

* "Svyaz'", No. 22, pp. 11–12, Moskva, 1925.

** [Russian Soviet Federated Socialist Republic.]

processing the data it was further established that the first human reaction to solar disturbances occurs in the nervous system /30/.

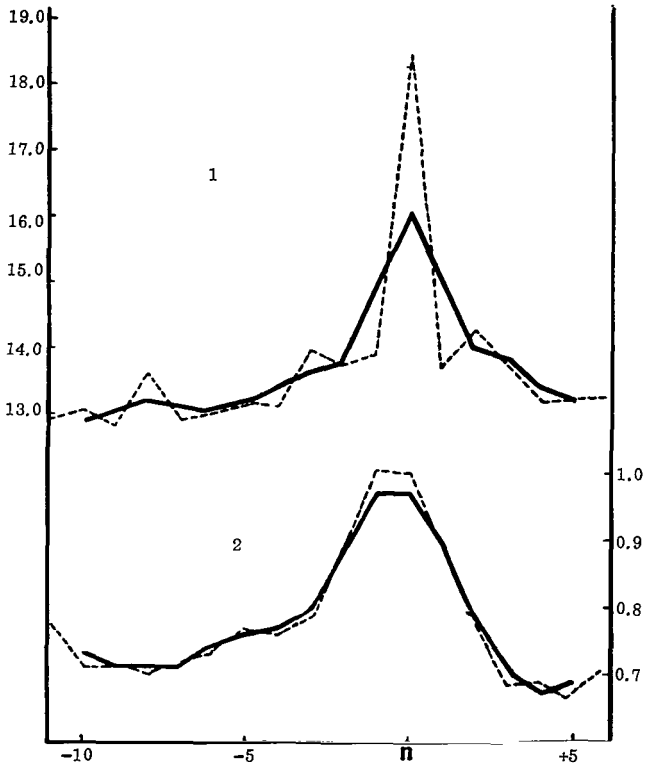


FIGURE 11. 1-Dynamics of mortality caused by diseases of the central and peripheral nervous systems, and of the cardiovascular system correlated with the 17-day periods following extraordinarily high mortality rates (n), in Copenhagen, Frankfurt-am-Main, and Zürich; mean of 60 periods: 4899 cases. 2-Corresponding course of magnetic activity (according to calendar dates) before and after the high mortality.

These extensive works indicated the general pattern in the phenomenon under consideration. The next step was the detailed analysis of daily statistical data. In one of our earlier investigations we noted the 27-day periodicity of certain statistical data coinciding with the synodic period of the Sun's rotations. On our recommendation, further statistical analysis was made of more than 200,000 deaths recorded over a period of many years, in the large cities of Western Europe, and caused by diseases of the brain, the nervous system, etc. All data were classified according to calendar dates with designation of the disease and cause of death, and were statistically analyzed by accurate methods and compared with the heliogeophysical index (B. and T. Düll /91, 92/).

Instrumental recording of geomagnetic activity follows the main solar phenomena with extraordinary accuracy, resulting in a correlation

coefficient very close to unity. The course of magnetic perturbances (world total) was therefore selected as the heliogeophysical index. A modification of the "superposed-epoch method" which we proposed more than 40 years ago was adopted for the statistical analysis of the data. The principle of the method is as follows: the maximum value for a given day of a certain period is recorded in the vertical axial column. To the left of this, the values for several preceding days are entered, and to the right, the values for several subsequent days. Values for all the periods are obtained by summing up the vertical columns and averaging the numerical results. This method distinctly isolates the basic pattern eliminating noncharacteristic phenomena. Each entry in such a table corresponds to a certain calendar data, and also serves for recording other phenomena according to the calendar dates. The two resultant curves are compared and their correlation coefficient is calculated. These curves demonstrate a remarkable correlation of the phenomena under consideration (Figures 9–13).

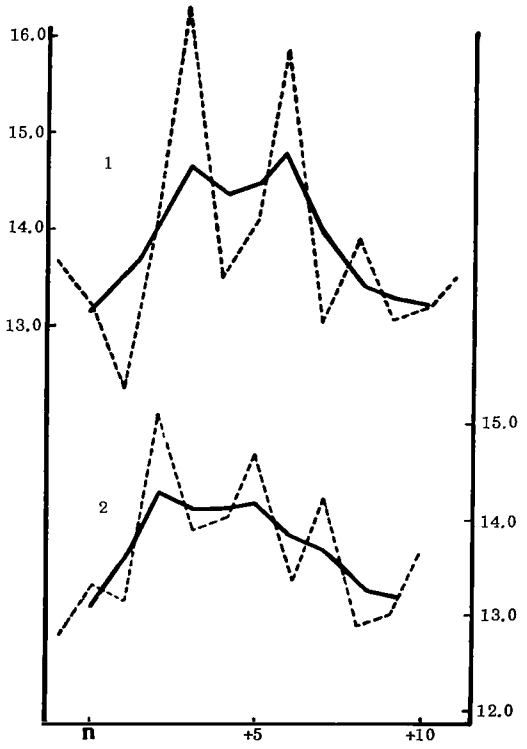


FIGURE 12. 1–Dynamics of mortality caused by diseases of the central and peripheral nervous systems, and of the cardiovascular system in Copenhagen, Frankfurt-am-Main, and Zürich; mean of thirty 12-day periods with most violent magnetic storms; 12,393 cases. 2–The same; mean of 60 periods: 24,739 cases.

The ordinate represents variations of mortality.

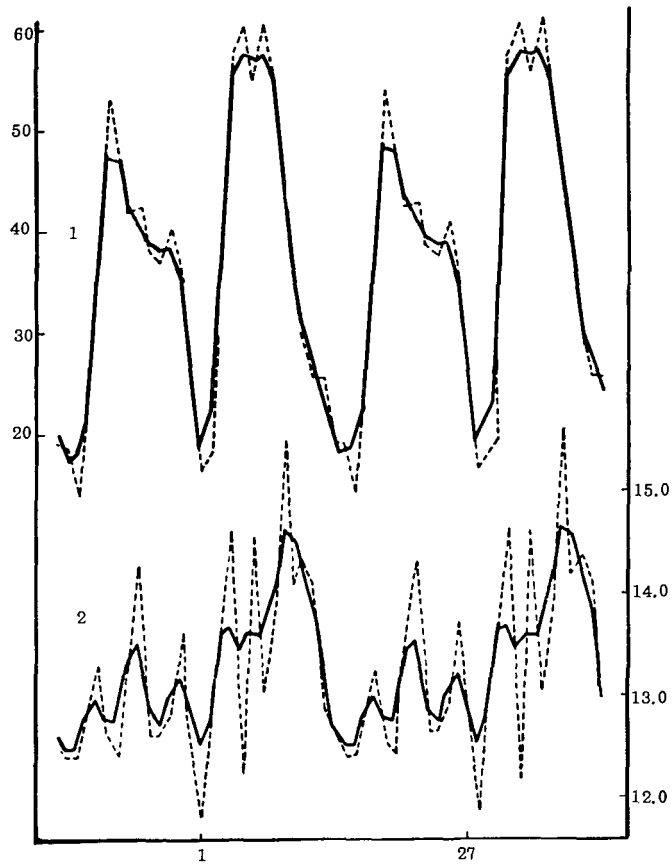


FIGURE 13. 1-World total of the course of magnetic disturbances correlated with the 27-day periods of the Sun's rotation; mean of 14 rotations. 2-Corresponding mortality (according to calendar dates) caused by diseases of the central and the peripheral nervous systems, and of the cardiovascular system, in Copenhagen, Frankfurt-am-Main, and Zürich; 4804 cases.

The ordinate represents variations in the magnetic field intensity of the Earth, and the mortality.

The time coincidence of the heliogeophysical and the pathological phenomena undoubtedly indicates an exceptionally close relationship between them, i. e., a certain heliogeophysical factor synchronously provokes a marked increase in mortality at various places on the planet. The correlation coefficient for some of these curves is very close to unity.

From the time distribution of mortality we may conclude that the number of deaths caused by certain diseases at a given moment depends mainly upon the frequency and intensity of the specific solar radiation.* It would be erroneous to assume that the ailments or deaths were caused by these radiations. The latter may only provide the impetus, which, in the

* There are no available scientific data suggesting the possible effect on mortality of disturbances in the terrestrial magnetic field.

presence of suitable conditions in the organism, causes its death. Thus, the periods of high mortality are determined by the solar factor, whereas the number of deaths is determined by the susceptibility of the given organism to this factor. Consequently, distinction should be made between: (1) the presence at the given moment of the external factor; and (2) the tendency of the organism to react pathologically to this factor /19, 20, 42, 43, 47, 49, 50, 54/. Attention should be focused precisely on the action of these sudden bursts of Z-radiation, and perturbations of the electromagnetic field, at times arriving singly, and at others in rapid succession. These bursts may throw the physiological mechanism out of balance without giving them the time needed to recover, and the persistent unidirectional course of these bursts leads to the death of the ailing organism.

The sudden Z-radiations of the Sun kill the weak, worn-out, senile organisms, but not healthy people. Patients with serious disturbances of the nervous system and of its core— the brain— die most rapidly. Patients suffering from cardiovascular diseases die somewhat later. These are followed by deaths due to grave diseases of other internal organs. Thus, the Z-radiations first strike the central nervous system, which is the most sensitive to external influences and reacts most intensely to them. The life of a young patient with a serious infectious disease is endangered only in the critical days of the disease, whereas in old age the range of dangerous nosologic units expands. If a patient is protected against these radiations during the critical days of his disease, he may continue to live for many more years.

The struggle against premature death is the struggle for enriching mankind with major cultural and material values. The subject is usually closed with the remark "The heart has failed." The data presented in this paper shed new light on the problem of sudden, or premature death. This problem seems to be much more serious and complex than is currently thought.

Let us now consider the physiological mechanism of sudden Z-radiation, and of the biophysicochemical disturbances produced by this cosmic factor in the entire living organism or in its individual organs.

The specific reaction of volutin granules in Corynebacteria to solar "flares" has already been mentioned. This was the first step toward the study of this subject, some 30 years ago. It may be assumed that the impact of Z-radiation acts directly on the central nervous system. The Z-radiation may also affect the protein-colloid system of blood, lymph, and cytoplasm inducing colloidal-electrical changes that involve coagulation of the colloids, thereby leading to death under certain pathological conditions of the organism. It is known that a minimum amount of electromagnetic energy may markedly lower the stability of the dispersed phase of certain colloidal fluids. Experiments have shown that radio waves from telegraphic transmitters caused relatively rapid precipitation of the solid phase of certain colloids, yet the field intensity is only of the order of 0.001 to 0.00001 of the intensity of the so-called electrical interference. When placed in sheet-iron chambers the same colloids were not affected by radio transmitters (Wilke and Müller). It has been known for a long time that milk curdles considerably faster on days with marked atmospheric-electrical disturbances (thunderstorms) than on other

days. It was experimentally proved that the curdling is quite independent of bacterial processes. Evidently, under the effect of the factors mentioned above, syneresis and disruption of the protein-colloid system occurs in the milk. Experimental coagulation of milk by treatment with short waves was reported, thus excluding from the process any thermal phenomena (Kerber, Goetinck). Similar observations were made on various gels and emulsions in which the suspended phases precipitated during thunderstorms (Wedekind and others).

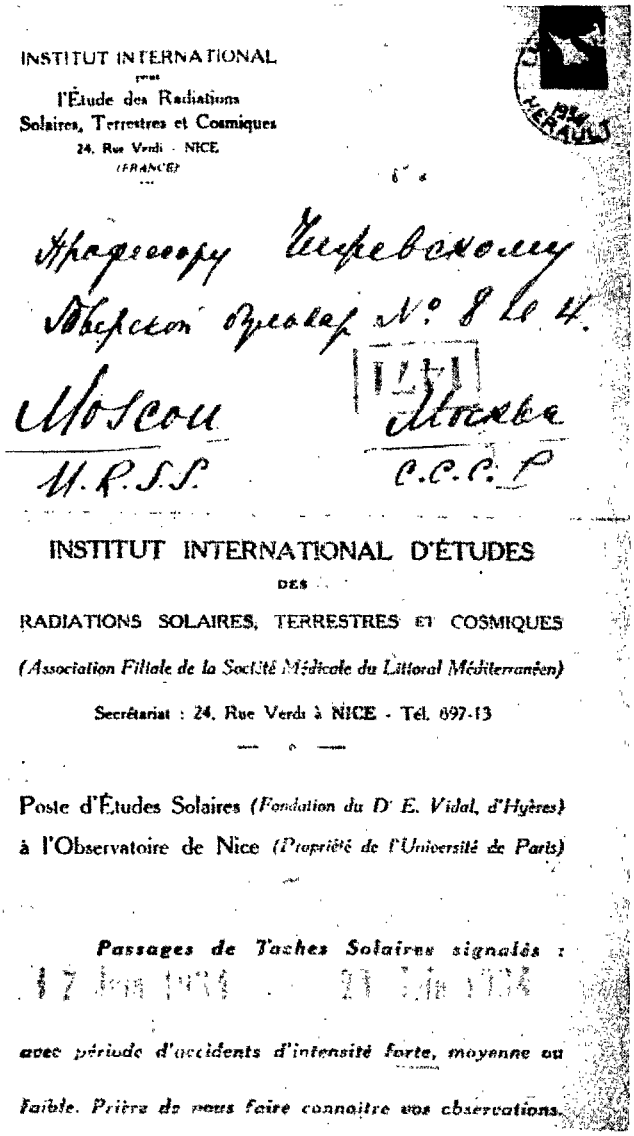
Extensive experimental studies of the effect on animals of different electromagnetic waves failed to solve this problem directly, although many authors reported unfavorable changes in certain physiological functions after short-wave irradiation (Schlifacke, Dainton). In Russia work in this interesting field was started by V. Ya. Danilevskii (1900–1901), and by V. Ya. Danilevskii and A. M. Vorob'ev (1928). In this connection, Academician V. Ya. Danilevskii wrote in his letter of 9 February 1928 to the author: "If we remember that we are separated from the Sun by a distance of only 107 Sun diameters, it is quite understandable that any disturbance of an electrical nature on the Sun must affect all creatures on Earth, since under certain conditions they act as resonators of these disturbances. I do not think that in general it is only the nervous system which is 'sensitive' in this respect. In principle, it cannot be denied that any living protoplasm may react functionally to these disturbances. When I observed in my latest experiments how sharply a nerve reacted to electromagnetic waves which did not excite but merely modified its physiological properties, I was immediately reminded of your theory."

It is possible that the radiations in which we are interested lie within the range of ultrashort radio waves, i. e., between centimeters and hectomicrons. These ultrashort radio waves are bounded on one side by decimeter radio waves and on the other by decamicron infrared rays. The assumption that the nervous system is endowed with "receivers" of millimetric radio waves is theoretically sound (Academician A. V. Leontovich).

The effect of electromagnetic waves of various wavelengths was studied, almost without exception, on healthy animals. In 1932–1933, we performed experiments which were basically different. Rabbits were treated with a sublethal dose of poison. The animals did not perish but were seriously affected by the poison. Another group of animals were inoculated with a rapidly developing infection. When placed in the field of electromagnetic waves generated by the mass radiator designed by Prof. A. A. Glagoleva-Arkad'eva, most of these animals (80%), severely ill beforehand, perished within a short time. The control animals placed in a grounded metal cage failed to respond to treatment with electromagnetic waves and the disease or poisoning took its expected course. These experiments demonstrated that: (1) the electromagnetic radiations proved to be incomparably more injurious for the severely ill animals than for healthy animals; and (2) that metal screens may protect the organism against these electromagnetic radiations.

These studies prompted me, at that time, to suggest the publication of an astronomical bulletin for hospitals and clinics that would warn them at least 5 or 6 days in advance of the passage of disturbed areas through the Sun's central meridian. This measure was implemented by the International Institute for Radiation Studies (Institut internationale d'études des radiations solaires, terrestres, et cosmiques), and for several years

these astronimical bulletins were dispatched to all large medical institutions in France (Figure 14). According to Prof. M. Faure (Paris) this measure saved tens of thousands of human lives in France alone over a period of 3 to 4 years /83/.



INSTITUT INTERNATIONAL
pour
l'Étude des Radiations
Solaires, Terrestres et Cosmiques
24, Rue Verdi - NICE
(FRANCE)

Профессору Чижевскому
Институт Эволюц. № 8 Le 4.
Москва
U.R.S.S.
Москва
C.C.C.P

INSTITUT INTERNATIONAL D'ÉTUDES
DES
RADIATIONS SOLAIRES, TERRESTRES ET COSMIQUES
(Association Filiale de la Société Médicale du Littoral Méditerranéen)
Secrétariat : 24, Rue Verdi à NICE - Tél. 697-13

Poste d'Études Solaires *(Fondation du Dr E. Vidal, d'Hyères)*
à l'Observatoire de Nice *(Propriété de l'Université de Paris)*

Passages de Taches Solaires signalés :
17 Juin 1934 ... 21 Juin 1934

avec période d'accidents d'intensité forte, moyenne ou faible. Prière de nous faire connaître vos observations.

FIGURE 14. Astronomical bulletin of the International Institute of Radiation Studies distributed over a period of several years to all major medical institutions in France.

On the basis of our work in the field of epidemiology and statistics, and proceeding from the principle that the coincident mortality is caused by the changes induced by solar Z-radiations in the protein-colloid equilibrium of the blood, lymph, and tissue fluids, M. Takata /97/ began, in 1935, a search for a sensitive test for the precipitation of protein fractions from the serum. This research proved that certain solar radiations have a clear-cut, extremely potent effect on human blood, and that their activity could not be ascribed to any of the known components of the solar spectrum, from ultraviolet to infrared. The average normative value of this reaction was 31.5. The F reaction (Flockungszahl-reaction) revealed that the variations were directly linked to the position of the Sun and, most important, to the passage of the disturbed areas on the Sun through its central meridian. This reaction clearly displayed the 11-year cycles and the 27-day synodic periods of solar rotation. The F reaction induced precipitation of protein bodies from the human blood serum, whereby the stronger the specific action of the Sun, the more intense the flocculation. This phenomenon was designated "catastrophic flocculation" when the reaction index increased to 80. This F reaction of the blood can be revealed only when both the blood donor and the person sampling the blood are electrically insulated from the Earth. In 1936–1952 the findings of M. Takata and his co-workers T. Murazugi and A. Takata were fully corroborated by many scientists in various countries (Girkage, Hofbauer, Ebergeni, Isbruch, Koller and Müller, Seitz, Äsler and Both, Condorelli, Cafiero, Beckmann, and others).

In 1931–1950, while investigating the structural-morphological composition of native blood by special methods we repeatedly observed the unusual responsiveness of the hematopoietic organs to the specific radiation from the disturbed areas on the Sun. These extensive studies have been partially published in the first part of my book "Structural Analysis of Flowing Blood" (Strukturnyi analiz dvizhushcheisya krovi).*

More recently, the exceptionally strong effect of solar disturbances on hematopoiesis and on the dynamics of leukocytes have been demonstrated by the Soviet physician and hematologist, N. A. Shul'ts /100–102/. Advances in this field have been made by G. Piccardi (Florence), Professor of Physical Chemistry, and his numerous followers in many European countries. In October 1958, at the international symposium held in Brussels on problems concerning the relationships between solar and terrestrial phenomena, brilliant achievements have been reported in physical chemistry and biology based on hundreds of thousands of experiments designed to determine the rate of some simple chemical reactions and the precipitation of colloids.

Piccardi's research, supported by the organizing committee of the International Geophysical Year, deserves to be highly praised. These studies facilitated a direct approach to the clarification of one of the mechanisms of action on the organism of the chromospheric flares, and other disturbed areas on the Sun from which corpuscles of ultrahigh energies and electromagnetic waves of different frequencies bombard the Earth.

It should be mentioned that the remedies used in current therapeutics cannot abate the changes induced in the organism by Z-radiations. Only further detailed studies in this field will expose the

* Published by the Academy of Sciences of the USSR, Moscow. 1959.

finer mechanisms of action of Z-radiation on living matter. If Z-radiation is proved to act on the protein-colloidal phase of the patients' blood inducing irreversible precipitation of the protein from the plasma or from plasmatic formations, it might become necessary to seek means of preserving the dispersed phase in a stable state. In this case protection against Z-rays will be limited to measures aimed at maintaining the electrical charges of biocolloids at the required level. At present, it is possible to solve this problem satisfactorily.

Conversely, if it is assumed that the Z-radiation lies in the region of radio and ultrashort radio waves, the thickness of a metallic screen for the protection of patients against these radiations is easily calculated. On the basis of these premises I published a series of articles /66, 67/, in the medical press, in 1937, indicating the need to provide all hospitals with electrically grounded, shielded wards impenetrable by Z-rays. These wards should be shielded on all sides from the outer environment by welded metal sheets of a specified thickness, and entered into from vestibules similarly shielded and equipped, with double doors so that the door to the patient's room is opened only after the one to the vestibule is closed. These wards should be supplied with artificial daylight, adequate ventilation or, preferably, conditioned and ionized air. In all other respects they need not differ from ordinary wards. Erection of such shielded wards presents no difficulties for modern engineering. For ultrashort waves the screens should be correspondingly thicker. Finally, underground wards can be built which are covered with a layer of soil sufficiently thick to absorb the entire spectrum of Z-radiation. Seriously ill patients whose lives might be endangered on days of solar storms and hurricanes should be transferred to these wards, in accordance with the forecasts of the astronomic "Sun bureau," or the bulletins issued by heliomicrobiological laboratories.

Thus, medicine is facing a new problem of extraordinary practical significance, requiring thorough study of the protection of severely ill patients on certain days against sudden Z-radiations, either by artificial stabilization of the plasma proteins, or by shielding.

We expound on the necessity of extensive implementation of prophylactic measures in our hospitals, and at the same time obstinately refuse to take notice of achievements in the related fields of science. No progress will be achieved under these conditions. The time has come to channel our efforts toward the elaboration of prophylactic methods based on the achievements of all fields of modern science.

The correlation of sudden and premature deaths with the specific radiations discussed in this paper calls for comprehensive statistical, theoretical, clinical, and experimental studies with the participation of heliophysicists, physicists, biophysicists, chemists, physiologists, and physicians. This subject merits the full attention of government organizations which plan and coordinate scientific research.

In 1963 we entered th period of decline of solar activity. The next increase in solar activity will occur in 1965–1966, and it is desirable that science will have provided an accurate evaluation of the concepts and facts presented in this article, and that it will have made an attempt at practical implementations of the suggestions advanced herewith. Research in this

important subject obviously calls for a well-equipped scientific research laboratory staffed with highly qualified experts in astrophysics, chemistry, physiology, and medicine.

REFERENCES

1. CHIZHEVSKII, A. L. Periodicheskoe vliyanie Solntsa na biosferu Zemli (Periodic Influence of the Sun on the Earth's Biosphere). — Doklad, chitannyi v Moskovskom arkheologicheskom institute, reprint, pp. 292—304. Moskva. Oct. 1915
2. CHIZHEVSKII, A. L. Sinkhronisticheskie tablitsy (Synchronous Tables), MS, pp. 1—768. Moskva. 1918.
3. CHIZHEVSKII, A. L. Penetrantnoe i solnechnoe izluchenie i zhizn' (Penetrating and Solar Radiation and Life). In Russian, French and German, lithographic reprint, pp. 1—34, Kaluga. 1919.
4. CHIZHEVSKII, A. L. Astronomiya, fiziologiya i istoriya (Astronomy, Physiology and History). — Trudy nauchnoi konferentsii, reprint, pp. 1—78. Moskva. 1921.
5. CHIZHEVSKII, A. L. Vliyanie periodicheskoi deyatel'nosti Solntsa na vozniknovenie i razvitie epidemii (Influence on Epidemics of the Sun's Periodic Activity), Dolozheno v Zoologicheskom muzee Pervogo Moskvoskogo universiteta, lithographed, pp. 1—21. Kaluga. 1922.
6. CHIZHEVSKII, A. L. Fizicheskie faktory istoricheskogo protsessa (Physical Factors of the Historical Process), Monograph, pp. 1—72. Kaluga. 1924.
7. CHIZHEVSKII, A. L. Vliyanie periodicheskoi deyatel'nosti Solntsa na organicheskii mir (Influence on the Organic World of the Sun's Periodic Activity). — "Khochu Vse Znat'," No. 4, p. 155. Moskva. 1926.
8. CHIZHEVSKII, A. L. Sovremennaya astrologiya (Contemporary Astrology) — Ogonek, No. 17. 1926.
9. CHIZHEVSKII, A. L. Epokha revolyutsii v prirode (Epoch of Revolution in Nature). — Ogonek, No. 25. 1926.
10. CHIZHEVSKII, A. L. Gripp i solnechnye pyatna (Grippe and Sunspots). —Ogonek, No. 14. 1927.
11. CHIZHEVSKII, A. L. Solntse i rost derev'ev (Sun and the Growth of Trees). — Krest'yanskii Zhurnal, p. 30. Moskva. 1927.
12. CHIZHEVSKII, A. L. Astrologiya nashikh dnei (Astrology in Our Times). — Klimat i Pogoda, Nos. 5—6, p. 129. Leningrad. 1927.
13. CHIZHEVSKII, A. L. O sootnoshenii mezhdu periodicheskoi deyatel'nost'yu Solntsa i epidemiyami kholery i grippa (Interrelation of Periodic Solar Activity and Epidemics of Grippe and Cholera). — "Russko-nemetskii Meditsinskii Zhurnal," N. A. Semashko and Prof. F. Krauz, editors, Vol. 3, No. 9, pp. 511—539. Berlin. 1927.
14. CHIZHEVSKII, A. L. Faktor, sposobstvuyushchii vozniknoveniyu i rasprostraneniyu psikhozov (An Instrumental Factor in the

Emergence and Spreading of Psychoses).— Ibid., Vol. 4, No. 3, pp. 101–131. 1928.

15. CHIZHEVSKII, A. L. Modifikatsiya nervnoi vozbudimosti pod vliyaniem perturbatsii vo vneshnei srede (Modification of Nervous Excitability Induced by Environmental Disturbances).— Ibid., No. 8, pp. 431–452, and No. 9, pp. 479–518. 1928.
16. CHIZHEVSKII, A. L. O periodichnosti evropeiskogo vozvratnogo tifa (Periodicity of European Relapsing Fever).— Ibid., No. 12, pp. 685–694. 1928.
17. CHIZHEVSKII, A. L. Nashe povedenie i priroda (Nature and Our Behavior).— Znanie-Sila, No. 17, p. 186. 1928.
18. CHIZHEVSKII, A. L. O vliyanii izmeneniya kolichestva luchistoi energii Solntsa na povedenie kollektivov zhivotnykh (Influence of Variations in the Solar Radiant Energy upon the Behavior of Animal Groups).— Trudy Prakticheskoi laboratorii po zoopsikhologii Glavnauki NKProsa, No. 1, pp. 39–41. Moskva. 1928.
19. CHIZHEVSKII, A. L. *Epidemicheskie katastrofy i periodicheskaya* deyatel'nost' Solntsa (Catastrophic Epidemics and the Periodic Activity of the Sun), Monograph, pp. 1–172. Moskva. 1930.
20. CHIZHEVSKII, A. L. Pro periodychnost' zahal'noi smertnosty (Periodicity of General Mortality).— Profylaktychna Medytsyna, pp. 36–46. Khar'kov. [In Ukrainian.]
21. CHIZHEVSKII, A. L. Teoriya geliotaraksii (Theory of Heliotaraxy), reprint, pp. 1–10. Moskva. 1930.
22. CHIZHEVSKII, A. L. Atmosfernoe elektrichestvo i epidemii (Atmospheric Electricity and Epidemics).— Trudy Tsentral'noi Nauchno-Issledovatel'skoi Laboratorii Tonifikatsii, Vol. 3, pp. 293–310. Voronezh. 1934.
23. TCHIJEVSKY, A. L. Effet des facteurs physiques de la nature sur les éléments nerveux et sur l'activité nerveuse des animaux et de l'homme. Rapport fait au Laboratoire de Zoopsychologie, pp. 1–70. Moscou. 1925. Voir: Traité de climatologie biologique et médicale, Vol. 1, p. 672. Paris. 1925.
24. TCHIJEVSKY, A. L. Über die Wechselbeziehungen zwischen der periodischen Tätigkeit der Sonne und den Cholera und Grippe Epidemien.— Deutsch-Russische Medizinische Zeitschrift. Schriftleitung: Geh. Rat. Prof. Dr. med. Kraus (Berlin) und Prof. Dr. med. N. A. Semaschko (Moskau), Vol. 3, No. 9, p. 539. Berlin. 1927.
25. TCHIJEVSKY, A. L. Physical Factors of the Historical Process.— Paper Read by Smitt at the Annual Meeting of the American Meteorological Society, Philadelphia, 30 December 1926. N. Y. 1927.
26. TCHIJEVSKY, A. L. Humanity and Sunspot Activity.— Paper Presented by Prof. V. P. de Smitt, New York Academy of Science, 7 March 1928; Bulletin of the New York Academy of Science, Vol. 21, No. 23, N. Y. 1928; see: de Smitt, V. P. —Journal of Cycle Research, Vol. 5, No. 4, pp. 89—103, N. Y., October 1956. Dewey, E. R. —Journal of Cycle Research, Vol. 9, No. 1, pp. 1—22. N. Y. January 1960.
27. TCHIJEVSKY, A. L. Kosmische Einflüsse, die Entstehung und Verbreitung von Massenpsychosen begünstigen.— Deutsch-Russische Medizinische Zeitschrift. Schriftleitung: Geh. Rat. Prof. Dr. med. F. Kraus (Berlin) und Prof. Dr. med. N. Semaschko (Moskau), Vol. 4, No. 3, pp. 89–117. Berlin. 1928.

28. TCHIJEVSKY, A. L. Über die Veränderung der Nervenerregbarkeit unter dem Einfluss der Perturbationen in der äusseren chemisch-physikalischen Umwelt. Versuch zum Studium der Kollektiv-Psychoneurologie. — Deutsch-Russische Medizinische Zeitschrift. Schriftleitung: Geh. Rat. Prof. Dr. med. F. Kraus (Berlin) und Prof. Dr. med. N. Semaschko (Moskau), Vol. 4, No. 8, pp. 405–430; No. 9, pp. 479–500. Berlin. 1928.
29. TCHIJEVSKY, A. L. Über die Periodizität des europäischen Typhus recurrens. — Deutsch-Russische Medizinische Zeitschrift. Schriftleitung: Geh. Rat. Prof. Dr. med. F. Kraus (Berlin) und Prof. Dr. med. N. Semaschko (Moskau), Vol. 4, No. 12, pp. 671–684. Berlin. 1928.
30. TCHIJEVSKY, A. L. Influence des oscillations diurnes et mensuelles de l'activité solaire sur les modifications de l'excitation nerveuse. — Comptes-Rendus des Séances de l'Académie des Sciences de Paris, Vol. 187, No. 2, p. 154, Paris. 1928; La Vie Universelle, Bulletin trimestriel de l'Association Internationale Biocosmique, No. 10, p. 186. Toulon. 1929.
31. TCHIJEVSKY, A. L. Théorie du moment élémentaire. — Rapport à la Société de Biodynamique, Séance 7 octobre 1929; Comptes Rendus de la Société de Biodynamique, Vol. 10, No. 11, p. 227, and Vol. 10, No. 12, pp. 251–258, Toulon. 1929; Société de Pathologie comparée et d'Hygiène générale. — Revue de Pathologie comparée et d'Hygiène générale, p. 974, Paris. 1930; Journal des practiciens. Paris. 1930.
32. TCHIJEVSKY, A. L. La signification énergétique. — Le Progrès Médical, No. 48, p. 2053. Paris, November 1929.
33. TCHIJEVSKY, A. L. La radiation cosmique, comme facteur biologique. Résultats des recherches expérimentales de l'influence de la radiation cosmique solaire et astrale sur les cellules et les tissus. — Bulletin de l'Association Internationale Biocosmique, No. 13, pp. 245–250. Toulon. 1929.
34. TCHIJEVSKY, A. L. La corrélation. — Revue Scientifique, No. 9, p. 277, Paris. 1929; La Vie Universelle, No. 11, p. 211. Toulon. 1929.
35. TCHIJEVSKY, A. L. L'application possible de quelques radiations cosmiques dans les buts thérapeutiques. — Astrosophie, Vol. 4, No. 3. Carthage, November 1929.
36. TCHIJEVSKY, A. L. Influence de l'activité solaire. Discussion. — La Côte d'Azur Médicale, Vol. 11, No. 12, pp. 252–257. Toulon, December 1929.
37. TCHIJEVSKY, A. L. Cosmic Energy as a Factor in Human History. — The Seer, Vol. 1, No. 1, p. 37. Carthage, January 1930.
38. TCHIJEVSKY, A. L. A propos de l'influence de l'activité solaire périodique. — La Côte d'Azur Médicale, Vol. 11, No. 3, pp. 57–62. Toulon. 1930.
39. TCHIJEVSKY, A. L. Energie cosmique. La part des facteurs cosmiques dans la fondation de la vie de l'humanité. — L'Astrosophie Vol. 4, No. 2, pp. 84–99. Carthage. 1930.
40. TCHIJEVSKY, A. L. Les forces excitatrices du cosmos et notre conduite. — Bulletin de l'Association Internationale Biocosmique, No. 14, p. 285. Toulon. 1930.

41. TCHIJEVSKY, A. L. The Correlation Betweenthe Variations of the Sunspot Activity and the Rise and Spreading of Epidemics.— Congresso international de Hidrologia, Climatologia et Geologia medicas. Programa das Sesseos Scientificas, 2 Sesseo. p. 5. Lisboa. 1930.
42. TCHIJEVSKY, A. L. Natalité des hommes et la tension de l'activité solaire.— La Côte d'Azur Médicale, Vol. 11, No. 9, p. 230. Toulon. 1930.
43. TCHIJEVSKY, A. L. Les périodes solaires et la mortalité. La Côte d'Azur Médicale, Vol. 11, No. 9, p. 232. Toulon. 1930.
44. TCHIJEVSKY, A. L. Les mutations et les accroissements brusques de l'activité solaire (l'électricité atmosphérique).— La Côte d'Azur Médicale, Vol. 11, No. 12, p. 302. Toulon. 1930.
45. TCHIJEVSKY, A. L. Nécessité d'organiser un institut international pour étudier la conduite, Manuscript 1922–1923.— Rapport à la Société de Biodynamique 1926. La Côte d'Azur Médicale, Vol. 12, No. 10, p. 255. Toulon. 1930.
46. TCHIJEVSKY, A. L. L'émigration de tous les pays en Amérique.— La Vie Universelle, No. 16, p. 6. December 1930.
47. TCHIJEVSKY, A. L. Taches solaires et la mortalité.— Rapport à la Société d'Astronomie de Toulouse. October 1930.
48. TCHIJEVSKY, A. L. Loi de la compensation quantitative dans les fonctions de la biosphère en relation avec les variations énergétiques de l'activité solaire.— Communication à la Société de Biodynamique. Paris. 1930; Publié dans la Revue Scientifique (Revue rose illustrée), Vol. 73, pp. 532–534. Paris, 24 August 1935.
49. TCHIJEVSKY, A. L. L'activité solaire et la mortalité.— Rapport à l'Académie des Sciences du Var. Séance du mercredi 2 avril 1930.— Bulletin de l'Académie du Var., Vol. 98, p. 5. Toulon. 1931.
50. TCHIJEVSKY, A. L. Influence des variations de l'activité solaire sur la natalité et sur la mortalité.— Rapport à l'Académie des Sciences du Var., Séance du mercredi, 7 mai 1930. Bulletin de l'Académie du Var., Vol. 98, p. 6. Toulon. 1931.
51. TCHIJEVSKY, A. L. and S. I. IVANTCHENKO. La corrélation entre les accès du paludisme (malaria) et le degré de tension de l'électricité atmosphérique. — Revue de Pathologie comparée et d'Hygiène generale, Vol. 33, No. 446, pp. 1383-1391. Paris. November 1933.
52. TCHIJEVSKY, A. L. Effets de l'activité périodique solaire sur les phénomènes biologiques.— Traité de climatologie biologique et médicale (publié sous la direction du Prof. Dr. M. Piery). Manuscript de 1928. Masson et Co. Editeurs, Vol. 1, pp. 576–587. Paris. 1934.
53. TCHIJEVSKY, A. L. Action de l'activité périodique solaire sur les épidémies.— Traité de climatologie biologique et médicale, No. 11, pp. 1034–1041. Paris. 1934.
54. TCHIJEVSKY, A. L. Action de l'activité périodique solaire sur la mortalité générale.— Traité de climatologie biologique et médicale, Vol. 11, pp. 1042–1046. Paris. 1934.

55. TCHIJEVSKY, A. L. L'homme et les radiations cosmiques. — Rapport à l'Académie des Sciences, présenté par le Président M. Rat. Séance du 4 juillet 1934. Revue des Radiations, No. 8, p. 215. Toulon. 1934.
56. TCHIJEVSKY, A. L. L'activité périodique du soleil et l'ionisation de l'air. — Gazette astronomique. Bulletin mensuel de la Société d'Astronomie d'Anvers, Vol. 21, No. 247, p. 87. Anvers. July 1934.
57. TCHIJEVSKY, A. L. Relations chronologiques des maladies épidémiques avec les variations de l'activité solaire. Manuscript. 1927. — Cosmobiologie, Revue Internationale, Vol. 11, pp. 85–90. Nice. 1935.
58. TCHIJEVSKY, A. L. Influence solaire. 1923. — Demain, Vol. 10, No. 8, p. 330. Bruxelles, December 1935.
59. TCHIJEVSKY, A. L. The Cosmic Causes of Diseases. — Rapport au III-e Congrès International de Pathologie Comparée. Comptes Rendus et Communication du III-e Congrès International de Pathologie Comparée du 15 au 18 avril 1936. Vol. 2 pp. 46, 588–597, 661. Athènes, 1936.
60. TCHIJEVSKY, A. L. Sur la connection entre l'activité solaire, l'électricité atmosphérique et les épidémies de la grippe. — Gazette des Hôpitaux, Vol. 109, No. 74, p. 1285. Paris, 16 September 1936.
61. TCHIJEVSKY, A. L. Über die kosmischen Ursachen von Krankheiten. — Zenit, Vol. 7, pp. 243–251. Düsseldorf. September 1936.
62. TCHIJEVSKY, A. L. Périodicité de la grippe et du soleil. — Demain, Vol. 11, No. 10. Bruxelles. 1936.
63. TCHIJEVSKY, A. L. Précis historique des relations entre les épidémies et les phénomènes météorologiques, géophysiques, et cosmiques. — Le Courrier d'Epidaure. Revue Médico-Littéraire, Vol. 3, No. 9, p. 3. Paris, November 1936.
64. TCHIJEVSKY, A. L. Les travaux des savants du XIX-e siècle sur les rapports entre les épidémies et les phénomènes météorologiques, géophysiques et cosmiques. — Le Courrier d'Epidaure. Revue Médico-Littéraire, Vol. 3, No. 10, p. 3. Paris, December 1936.
65. TCHIJEVSKY, A. L. Le milieu cosmo-tellurique et les organismes vivants. — Hippocrate. Directeur: Professeur Laignel-Lavastine, membre de l'Académie de Médicine de Paris, Vol. 4, No. 10, pp. 577-586. Paris, December 1936.
66. TCHIJEVSKY, A. L. La salle d'hôpital cuirassée pour la protection des malades contre les radiations solaires et cosmiques nuisibles. —Gazette des Hôpitaux, La Lancette Française, Vol. 110, No. 14, p. 221. Paris, 17 February 1937.
67. TCHIJEVSKY, A. L. Nécessité pour chaque hôpital d'être pourvu d'une salle revêtue de cuirasse, protégeant les malades contre certaines influences électromagnétiques et corpusculaires nuisibles du milieu cosmique. — La Côte d'Azur Médicale, Revue des Radiations, Vol. 18, No. 3, p. 58. Toulon, March 1937.
68. TCHIJEVSKY, A. L. De l'origine et de la nature de l'activité périodique du Soleil, laquelle conditionne les perturbations électriques et magnétiques dans l'atmosphère et l'écorce terrestre. — Hippocrate, Vol. 5, No. 1, pp. 23–38. Paris, January 1937.

69. TCHIJEVSKY, A. L. Les perturbations électriques, magnétiques et électro-magnétiques dans l'atmosphère et l'écorce terrestre sous l'influence des radiations spécifiques du soleil. — Hippocrate, Vol. 5, No. 2, pp. 87–101. Paris, February 1937; Vol. 5, No. 3, pp. 143–161. March 1937.
70. TCHIJEVSKY, A. L. Corrélation entre les oscillations de l'activité électrique du soleil et les épidémies du cholera asiatique. — Hippocrate, Vol. 5, No. 4, pp. 206–221. Paris. April 1937.
71. TCHIJEVSKY, A. L. Corrélation entre les oscillations de l'activité électrique du soleil et les épidémies de la diphtérie. — Hippocrate, Vol. 5, No. 5, pp. 257–268. Paris, May 1937.
72. TCHIJEVSKY, A. L. Corrélation entre les oscillations de l'activité électrique du soleil et de l'électricité atmosphérique et les épidémies de la méningite cérébrospinale et la poliomyélite. — Hippocrate, Vol. 5, No. 5, pp. 269–276. Paris, May 1937.
73. TCHIJEVSKY, A. L. Corrélation entre les oscillations de l'activité électrique du soleil et les épidémies de la peste. — Hippocrate, Vol. Vol. 5, No. 6, pp. 321–333. Paris, June 1937.
74. TCHIJEVSKY, A. L. Corrélation entre les oscillations de l'activité électrique du soleil et les épidémies de la fièvre récurrente. — Hippocrate, Vol. 5, No. 6, pp. 334–342. Paris, June 1937.
75. TCHIJEVSKY, A. L. Corrélation entre les oscillations de l'activité électrique du soleil et les épidémies de la grippe. — Hippocrate, Vol. 5, No. 7, pp. 402–414. Paris, September 1937; No. 8, pp. 449–465, October 1937.
76. TCHIJEVSKY, A. L. Corrélation entre les oscillations du potentiel de l'électricité atmosphérique et le paludisme. — Hippocrate, Vol. 5, No. 9, pp. 513–523. Paris, November 1937.
77. TCHIJEVSKY, A. L. Corrélation entre les oscillations de l'activité électrique du soleil et diverses épidémies. — Hippocrate, Vol. 5, No. 10, pp. 577–592. Paris, December 1937.
78. TCHIJEVSKY, A. L. L'activité corpusculaire électromagnétique et périodique du soleil et l'électricité atmosphérique comme régulateurs de la distribution dans la suite des temps des maladies épidémiques et de la mortalité générale. — Acta Medica Scandinavica, Vol. 91, Fasc. 6, pp. 491–522. Stockholm. 1937.
79. TCHIJEVSKY, A. L. Théorie de la formation de matière organique dans un champ électrique (impulsif ou alternatif). — Présenté à l'Institut de Plasmogenia, Directeur: Prof. Dr. A. L. Herrera, tirage à part. Mexico. October 1937.
80. TCHIJEVSKY, A. L. Les épidémies et les perturbations électromagnétiques du milieu extérieur. Monographie, pp. 1–240. — Collection Hippocrate, Edt. (Publié sous la direction du professeur dr. méd. Laignel-Lavastine). Paris. 1938.
81. TCHIJEVSKY, A. L. Facteurs électriques du milieu extérieur et les microorganismes. — Bulletin de l'Association des diplomés de Microbiologie de la Faculté de Pharmacie de Nancy, No. 16, pp. 30–62. Nancy, May 1938. Monographie, pp. 1–36. Edition de la Société d'Impressions typographiques. Nancy. 1938.

82. TCHIJEVSKY, A. L. Les oscillations périodiques des facteurs électriques du milieu ambiant et la virulence des microorganismes pathogènes. — Rapport présenté au 2-me Congrès International sur les rythmes biologiques, 25 and 26 August 1939. Programme, p. 4. Utrecht. 1939.
83. TCHIJEVSKY, A. L. About Cosmobiology. — Report of the 12 September 1939, International Congress of Biophysics and Biocosmics. Programme of Congress. p. 7, N. Y., 1939; Revue des Radiations, Vol. 21, No. 3, p. 35. Toulon, March. 1940.
84. TCHIJEVSKY, A. L. Cosmobiologie et rythme du milieu extérieur. — Rapport fait au 2-me Congrès International sur les rythmes biologiques. 25 and 26 August 1939. Utrecht. Verhandlungen der zweiten Konferenz der Internationalen Gesellschaft für biologische Rythmusforschungen; am 25 und 26 August 1939. Utrecht (Holland), pp. 211–227. Supplementum der Acta Medica Scandinavica, No. CVIII, Stockholm. 1940.
85. ARRHENIUS, S. A. Vliyanie kosmicheskikh uslovii na fiziologicheskie otpravleniya cheloveka (Influence of Cosmic Conditions on Human Physiology). — Nauchnoe Obozrenie, No. 2, pp. 261–298, Sankt-Peterburg. 1900.
86. VEL'KHOVER, S. T. — Zhurnal Mikrobiologii, Epidemiologii i Immunobiologii, Vol. 15, No. 6. Moskva. 1936.
87. VEL'KHOVER, S. T. — Trudy Kazanskogo Nauchno-Issledovatel'skogo Instituta Teoreticheskoi i Klinicheskoi Meditsiny, No. 3. Kazan'. 1936.
88. VOGRALIK, G. F. Uchenie ob epidemicheskikh boleznyakh (Study of Epidemic Diseases), Tomsk. 1935.
89. DUBOIS, R. Bacterial Cell. [Russian translation. 1948.]
90. DÜLL, B. and T. DÜLL. — Deutsche Medizinische Wochenschrift, Vol. 3, No. 95, Berlin. 1935.
91. DÜLL, B. and T. DÜLL. — Medizinische-meteorologische Statistik. Berlin. 1937.
92. DÜLL, B. and T. DÜLL. — Bioklimatische Beiblätter, Vol. 6, Nos. 2–3. Braunschweig. 1939.
93. COLLO, A. Une science nouvelle: la biométéorologie. — Science et Avenir, No. 148. Paris, June 1959.
94. PICCARDI, G. Symposium international sur les relations entre phénomènes solaires et terrestres en chimiephysique et en biologie, pp. 1–210. Bruxelles. 1960.
95. SADOV, A. A. Epidemicheskii gripp (Epidemic Grippe), Leningrad. 1927.
96. SADOV, A. A. K probleme etiologii i epidemiologii grippa (Contribution to the Etiology and Epidemiology of Grippe), Introduction to the Book "Etiology, Epidemiology, and Prevention of Grippe" by O Dujarrique de la Rivier. Leningrad. 1932.
97. TAKATA, M., T. MURAZUGI, and A. TAKATA. — Acta Serologica et Immunologica, Vol. 2, No. 2.
98. SCHOSTAKOVITCH, V. B. — Bioklimatische Beiblätter, Vol. 3. Berlin. 1936.

99. SHUL'TS, N. A. Sinfaznost' chastoty funktsional'nykh kolebanii kolichestva leikotsitov s kolebaniyami solnechnoi aktivnosti (Frequency of Leukocyte-Count Fluctuations in Phase with Fluctuations of Solar Activity).— Problemy gematologii i perelivaniya krovi, p. 41. Moskva. 1959.
100. SHUL'TS, N. A. Vliyanie kolebanii solnechnoi aktivnosti na krovetvorenie (Influence on Hematopoiesis of Fluctuations in Solar Activity).— Priroda, No. 6, p. 92. Moskva. 1959.
101. SHUL'TS, N. A. Dinamika izmenenii kolichestva leikotsitov v zavisimosti ot izmenenii solnechnoi radiatsii (Dynamics of Changes in Leukocyte Counts Correlated with Changes in Solar Radiation).— Laboratornoe Delo, No. 2, p. 36. Moskva. 1960.
102. CHULTZ, N. A. I globuli bianchi e le macchie solari.— Geofisica e meteorologia, Vol. 8, Nos. 5–6. Genova. 1960.
103. SHCHERBINOVSKII, N. S. Pustynnaya sarancha shistotserka (Desert Locust Schistocerca), Monograph, pp. 104–106. Moskva. 1952.
104. SMITT, de V. P. Physical Factors.— Journal of Cycle Research, Vol. 5, No. 4. N. Y., October 1956.
105. DEWEY, E. R. Tchijevsky's Index.— Journal of Cycle Research, Vol. 9, No. 1. N. Y., January 1960.
106. HORNER, S. L. Tchijevsky's Index.— Journal of Cycle Research, Vol. 9, No. 1. N. Y., January 1960.
107. GYURDZHIAN, A. A. Radiobiologicheskie problemy kosmicheskikh poletov (Radiobiological Problems of Space Flight).— In: Sbornik "Problemy kosmicheskoi biologii," Vol. 1, p. 73. Moskva. 1962.
108. TCHIJEVSKY, A. L. L'influenza delle grandi perturbazioni solari sull'origine e diffusione delle epidemie e sull'aggravamento delle malattie nervose e cardiovascolari.— Minerva Medica, Vol. 54, No. 38, p. 42. Ferrara, 12 May 1963.
109. TCHIJEVSKY, A. L. Über die Methode des Studiums des Zusammenhangs zwischen der periodischen Tätigkeit der Sonne und den Epidemien des Typhus recurrens.— VIII International Conference of the Society for Biological Rhythm in Hamburg. September 1963.
110. CHIZHEVSKII, A. L. and Yu. G. SHISHINA. Vsemirnaya simpatiya (World Sympathy).— Nauka i Zhizn', No. 5, p. 82. Moskva. 1963.
111. CHIZHEVSKII, A. L. Nekotorye mikroorganizmy kak indikatory solnechnoi aktivnosti i predvestniki solnechnykh vspyshek (Certain Microorganisms as Indicators of Solar Activity and Forecasters of Solar Flares), Moskva. 1963.

A.L. Chizhevskii

PHYSICOCHEMICAL REACTIONS AS INDICATORS OF COSMIC PHENOMENA

It is well established that certain external factors, usually ignored, may influence the life activities of organisms, and even chemical or colloidal reactions.

However, physical chemistry and biology could never before provide such conclusive proof as now on the existence of certain cosmic phenomena, earlier "disregarded;" this development is the result of special laboratory experiments and of the vast statistical data collected.

Since 1951, and through the following decade, G. Piccardi, Professor of Physical Chemistry at the University of Florence has studied the effect on certain simple chemical reactions of the variations in solar activity associated with the appearance of sunspots, prominences, flares, etc. on the Sun's surface.

Piccardi's experiments aroused the interest of a significant number of scientists in different countries who agreed to conduct simultaneous investigations according to the same method. The results obtained were striking.

An international symposium on the influence of solar radiations on physicochemical reactions and biological phenomena was held at the Belgian Observatory in 8–10 October 1958. The exhaustive data presented at this symposium conclusively demonstrated the global and synchronizing effect of solar disturbances on physicochemical reactions, and on certain biological processes, confirming the basic premises of space biology.

We shall present a brief account of the most interesting investigations conducted by Prof. Piccardi and his school.

Temperature, pressure, humidity, illumination, and several other common variables can be controlled. In contrast, the appearance of sunspots, solar flares, or terrestrial magnetic storms is as unavoidable as the penetration of electromagnetic waves of certain wavelengths through the walls of our houses and through our own bodies. Similarly, we cannot prevent force fields from forming around us. Solar activity, sunspots, incidence and extent of solar eruptions and flares, electromagnetic fields, magnetic storms, and certain other phenomena, are all cosmic variables.

Since we are able to regulate only some of our experimental conditions we must revise our experimental methods. Valuable experiments are not limited to those yielding uniform results when carried out under ordinary and identical conditions. At present, there are means of explaining quite satisfactorily, the correlation of cosmic with terrestrial phenomena. In this respect, the statistical methods available render an invaluable service to science.

The impossibility of reproducing all experimental conditions compels us to reconsider this problem repeatedly. Since in many cases changes in cosmic conditions may significantly influence terrestrial processes, the times at which these changes occur should be carefully noted. The conditions prevailing at a given moment, or over a certain period of time may be partially defined by studying the astrophysical and geophysical phenomena. The day and the hour reflect the physical and cosmic situation which changes continuously.

The fundamental properties of the universe are reflected by periodic and nonperiodic variations. All existence on Earth is also subject to these variations. Depending upon the degree of the cosmic influence the terrestrial results of these changes may or may not be detected. Objects may differ in their sensitivity to cosmic factors.

Among the many chemical substances sensitive to cosmic influences are water and various colloid systems, which are the physical essence of life phenomena. The sensitivity of any chemical system to the influences of cosmic factors depends upon its structure, i.e., on the geometric and energy factors of its molecular structure and its intricate organization. The more we learn about the structure of water and colloids, the more this concept is strengthened.

In comparison with other substances the behavior of water is completely anomalous. A satisfactory theoretical explanation of this anomaly has not been presented thus far. The hypothesis advanced by Bernal and Fowler in 1933 that water has a pseudocrystalline structure, or a system of such structures, explained rather well some of the anomalies of water, although it was severely attacked by those who regarded water as merely a random aggregation of particles. This theory, however, was further developed and improved, and later enlarged by Pople (1951). In 1953, Harris and Adler used Pople's modification in calculating the dielectric constant of water at different temperatures. The calculated values were in complete agreement with the experimental results. None of the earlier theories had ever met with such success, and at present it is widely accepted that water has a definite structure. This is very important in the interpretation of cosmic influences.

There are grounds for assuming that certain physical factors may distort the structure of water without changing its chemical composition or its normal physical state. A change in the properties of water that does not involve any deviation from its normal state (temperature, pressure, etc.), nor the slightest change in its chemical composition is known as activation. The properties of water that depend upon its structure are readily distributed by the action of cosmic factors. Indeed, it was established that structural changes of water, and consequently of its finer properties, require very little energy.

In order to obtain statistical confirmation of cosmic influences Prof. Piccardi developed an experimental technique which may be repeatedly and universally replicated. The following conditions are required:

1. The possibility of stopping or weakening the action of cosmic factors with the aid of a metal screen covering the apparatus in which any accurately recorded reaction takes place.

2. The possibility of modifying the structure of water such as its activation. Water with modified structure will behave differently under the influence of cosmic factors than water with the usual structure.

The phenomenon under investigation can be thoroughly examined if numerous paired experiments are performed (under the metal screen and in activated water). The rate of precipitation of any chemical substance in the water can be recorded.

The chemical experiments are carried out while maintaining the following paired conditions:

Condition No. 1	Condition No. 2
Experiment P. Ordinary water subjected to the usual cosmic factors.	Ordinary water, subjected to modified cosmic factors.
Experiment F. Ordinary water subjected to the usual cosmic factors.	Activated water subjected to the usual cosmic factors.
Experiment D. Ordinary water subjected to the usual cosmic factors	Activated water subjected to modified cosmic factors.

In Piccardi's experiments a small, known amount of certain bismuth compounds was precipitated. The experiment was recorded continuously, since post-experimental calculations fail to indicate the kinetics of the system.

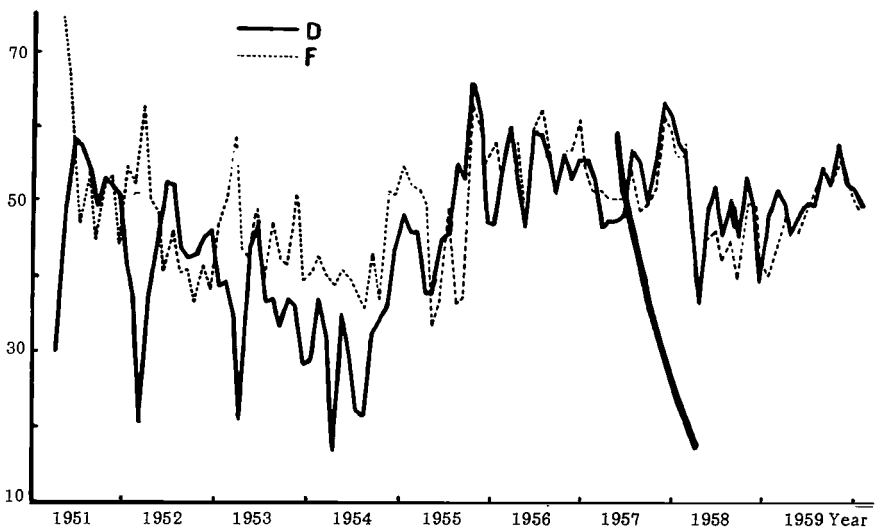


FIGURE 1. Dynamics of experiment D (solid curve) and F (dashed curve) in the course of nine years (according to Piccardi).

Since 1951 this kind of experiment has been performed in Florence, several times a day at the same time; the total number has already exceeded 250,000.

The results obtained are being studied by Dr. Becker of the Fraunhofer Institute in Florence, by Prof. Burkard of Graz University, by Prof. Berg of Cologne University (died in 1959), Dr. Mozetti of the Geographic Observatory at Trieste, engineer C. Capel-Boute of Brussels University, Doctor Meyer of Tübingen University and by Prof. Piccardi and his assistants.

It was found that experiment F was sensitive to solar flares and magnetic storms; however, experiment D depended upon the intensity of solar activity as determined by the Wolf number,* and therefore the recorded differences are of no fundamental significance (Figure 1). Experiment P also seemed to be connected with the solar activity, but this has not been confirmed as yet. It has been experimentally established that electromagnetic waves of certain wavelengths affect chemical experiments. A direct correlation exists between experiment D and the Wolf number (Figure 2).

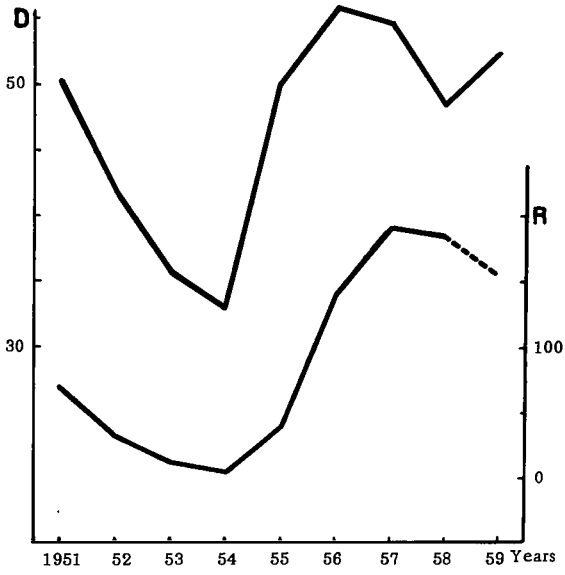


FIGURE 2. Dynamics of experiment D (upper curve) and of solar activity— Wolf numbers (lower curve). The correlation coefficient is 0.85 (according to Piccardi).

However, certain divergent results were recorded in the course of a year in experiment D. The lowest minimum usually occurred in spring in the middle of March, when no changes were recorded in the Wolf number. Therefore, experiment D indicates its "independence" of solar activity.

* The Wolf number is a quantity approximately proportional to the total area occupied by the sunspots at a given time. It is determined from the formula $W=10g+f$, where g indicates the number of sunspot groups, and f the number of single sunspots.— Ed.

The year-to-year variation of experiment D is cycloidal rather than sinusoidal. Taking into account the rotation of the Earth around the Sun, and the movement of the Sun toward the Hercules constellation, a varying helicoid was obtained, representing the movement of the Earth in the Galaxy (Figures 3, 4, 5). This movement is highly variable with respect to both direction and speed.

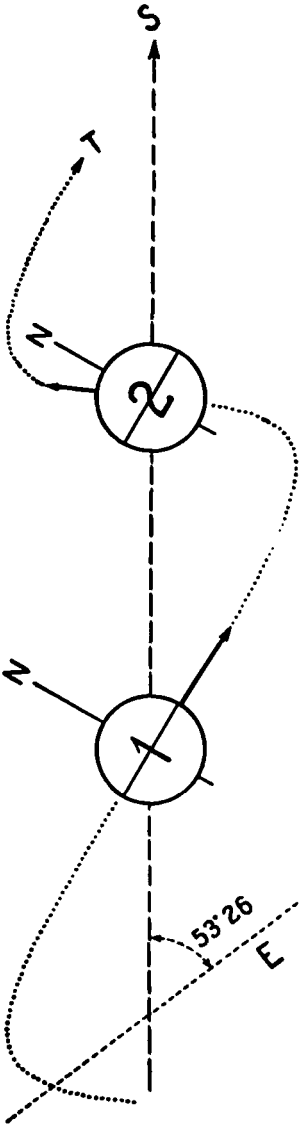


FIGURE 3. Movement of the Earth toward the center of the Galaxy: E–ecliptic plane in profile; S–apex of the Sun; N–direction of the Earth's North Pole; T–helicoidal movement of the Earth (according to Piccardi).

In March, the Earth moves in its orbit around the Sun at a maximum velocity of 45 km/sec in the equatorial plane, approximately toward the center of the Galaxy. In September, the Earth moves at its minimum velocity of 24 km/sec, in a direction almost perpendicular to that in March.

It is questionable whether these changes occur without affecting sensitive reactions on the Earth. The hypothesis advanced by Prof. Piccardi in 1954 emphasizes precisely these possible physical consequences of the Earth's movement in space, and suggests the asymmetry between the northern and southern hemispheres which was fully demonstrated by numerous experiments. Some experiments to this effect were performed in conjunction with the program of the International Geophysical Year in both hemispheres, at Brussels, Tübingen, Jungfraujoch, Vienna, Geneva, Trieste, Florence, Bari (Castellana Grotta), Libreville, Leopoldville, Fort-Dauphin (Madagascar), and on Kerguelen Island (Figure 6). Successful experiments were carried out at Sapporo and at Kumamoto (Japan), on Roi Baudouin Land (Antarctic), and on New Amsterdam Island. The recordings made at different points on our planet confirm the asymmetry mentioned above. The values of experiment F in the southern hemisphere are significantly lower than in the northern hemisphere, diminishing progressively toward the south.

Thus, Piccardi's hypothesis has practical value since it makes possible the forecasting of new and important details of cosmic factors.

Prof. Piccardi summarized his work as follows:

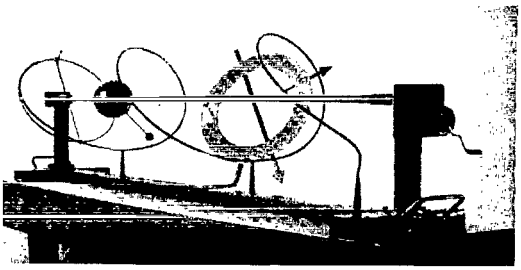


FIGURE 4. Model of helicoidal movement of the Earth in the Galaxy illustrating Piccardi's "solar hypothesis."

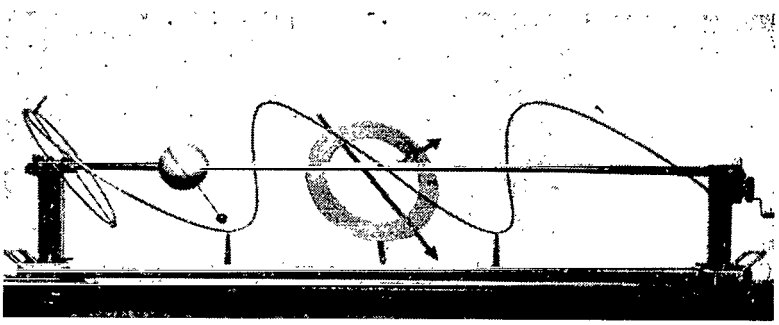


FIGURE 5. Model of helicoidal movement of the Earth in the Galaxy illustrating Piccardi's "solar hypothesis" (viewed from a different angle).

1. The correlation of cosmic phenomena with those on Earth are of interest not only in astrophysics and geophysics, but also in chemistry and physics.

2. The correlation of these phenomena can be investigated by studies of certain chemical reactions. In the future, this will make it possible to perform experiments of an unlimited diversity under a variety of conditions, since chemistry and physics have at their disposal innumerable systems sensitive to cosmic factors.

3. The suitability of chemical experiments has already been proved. They have helped to establish beyond doubt the effects of solar activity, solar flares, magnetic storms, etc. Moreover, they shed light on hitherto unknown phenomena, such as cycloidal changes with a minimum in March.

4. The pronounced effects of cosmic factors cannot be limited to inorganic colloids; they must equally affect the colloids of living organisms. Therefore, biologists and physicians should keep abreast of studies in cosmic activities.

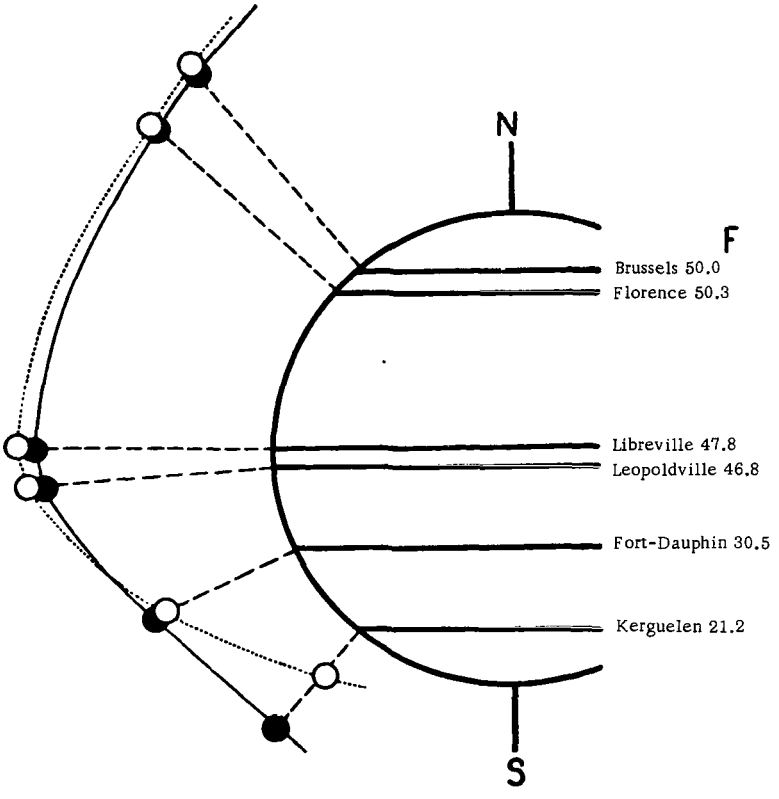


FIGURE 6. Distribution on the globe of the principal laboratories engaged in studies of the effect of solar flares on reaction F. On the left are the results of experiment F at different latitudes. The mean monthly values are correlated with the position of the laboratory with respect to the Sun and the intensity of its specific radiation. Attention is drawn to the asymmetry of the speed of reaction F in the two hemispheres. The dotted curve indicates the average value at the maximum asymmetry in September 1958; the solid curve indicates the average value for the two-year period, 1958–1959 (according to Piccardi).

REFERENCES

1. PICCARDI, G. Symposium international sur les relations entre phénomènes solaires et terrestres en chimie-physique et en biologie, pp. 1–210.— *Presses Académiques Européennes*. Bruxelles. 1960.
2. PICCARDI, G. The Problem of the Relationship betwen Spatial and Terrestrial Phenomena and Chemical Tests.— Atti della Fondazione Giorgio Ronchi. Anno XVI, No. 2, pp. 109–121. Firenze. March-April. 1961.
3. PICCARDI, G. The Chemical Basis of Medical Climatology.— Charles C. Thomas-Publisher. Springfield. Illinois. USA. 1962.

4. CAPEL-BOUTE, C. Tests chimiques et tests cliniques dans l'étude des facteurs géophysiques de l'ambiance.— IX Convegno della Salute. Stab. Poligrafico Artioli. Modena. 1962.
5. CAPEL-BOUTE, C. Incidents cosmiques en chimie-physique et en biologie.— Bulletin de la Fédération des Sociétés Scientifiques. N. VII, pp. 1–10. Bruxelles. 1962.

N.A. Shul'ts

EFFECT OF VARIATIONS IN SOLAR ACTIVITY ON THE NUMBER OF WHITE BLOOD CELLS

The first attempts at correlating variations in solar activity with certain biological phenomena were made in the nineteenth century (Herschel, Jevons, Shvedov).

However, the first comprehensive formulation of the relationship between solar outbursts and the living organism was published by the young Russian scientist, A. L. Chizhevskii, in 1915. He clearly demonstrated the close correlation of the 11-year solar cycle with numerous biological phenomena. Thorough research on this subject enabled him to publish a detailed work in 1918 partially in Russian and partially in other languages. This was followed by his medicostatistical and experimental investigations in the field of cosmic microbiology and cosmic epidemiology. These investigations were published in medical journals in 1927–1929, edited by Prof. Semashko. Chizhevskii's monograph on the subject was published in Moscow in 1930.

In 1926, Chizhevskii studied the effects of cosmic radiation on bacterial virulence and on tissue growth, and published his results in French and in English. This was the first work on the subject in the world literature. In 1928, Chizhevskii delivered a lecture at the Academy of Sciences in Paris on the effect of specific solar radiation (Z-radiation)* on the activity of the human nervous system, and on serious human diseases related to changes in this system (mainly neuropsychic and cardiac diseases). In 1929–1930 Chizhevskii's works in cosmic biology, microbiology, epidemiology, and medicine were published in many languages. In 1938 the Academy of Medical Sciences in Paris published Chizhevskii's work (edited by Laignel-Lavastine, member of the Academy).** Thus, priority of the USSR in this field was established.

Under the influence of these investigations several valuable researches were carried out in those years by the Soviet physicians Sadov, Ivashentsov, Ivanchenko, and Vel'khover, the geophysicist Shostakovich, and others. Tsiolkovskii was greatly impressed by Chizhevskii's work, and fully supported his research in a special article published in 1924. Studies in this important field only began outside the USSR in the 1940's (Budai, T. and B. Düll, Regnault, de Rudder, Bach and Schluck, Grayman, Takata and Murazugi, and others). Subsequently, this subject attracted the attention of Poumelleux and Viard, Giordano, Becker and Fering; in the USSR the subject was studied by Shcherbinovskii, Shul'ts, and others.

* [Chizhevskii's designation for a type of solar radiation.]

** [See /80/ on p. 305.]

Of exceptional interest is the research carried out by Piccardi who succeeded in correlating fluctuations in the precipitation and coagulation of colloidal solutions with the variations in solar activity. Piccardi's classical diagram (1958) [see p. 310] clearly shows a relationship between precipitation and the sunspot number in periods of decreasing and increasing solar activity. These variations in the course of chemical processes are known as Piccardi's chemical tests. At the present time, investigations of this problem are being conducted under the guidance of International Chemical Tests Committee organized in 1957.

The effect of solar factors on blood coagulation was thoroughly investigated by Caroli (1950), who revealed the singular role of solar flares in this connection, and established that fibrinolysis is enhanced twenty-four hours before a solar flare and reaches a maximum two days after it. According to A.I. Ol' (Ohl) (1954) the particles are emitted by chromospheric flares at a velocity exceeding 1000 km/sec, and require approximately two days to reach the Earth's surface.

Burkard (1955) recorded a correlation with the magnetic variations in an unshielded room, but the correlation could not be detected in a copper-shielded room. Becker (1955) reported that in ordinary unshielded laboratories the reactions in colloid systems (with activated water) were in phase with solar (chromospheric) flares of the second and third degree.

Takata and Murazugi (1941) reported significant increase in flocculation of blood serum two days after the passage of large groups of sunspots through the central meridian of the Sun.

Filk (1950) recorded fluctuations in the turbidity curves of the blood-serum protein fractions that were correlated with the variations in solar activity.

The studies carried out by Shul'ts (1951) on the effect of solar activity on the blood system revealed that fluctuations in differential leukocyte counts were in phase with solar activity variations, and enabled the author to test the latter by the differential counts.

These tests were as follows: "A"—functional leukopenia, "B"—relative lymphocytosis, and "C"—total test of functional leukopenia and relative lymphocytosis. The last test was adopted in order to confirm Kassirskii's premise that functional leukopenia and relative lymphocytosis are phenomena of the same order. This test proved to be the most sensitive indicator of the evident influence of solar activity on the number of leukocytes in the peripheral blood.

Chemical tests are easier to analyze statistically since they are less affected by the factors influencing the leukocyte counts (age, state of health, nutrition, work, previous diseases, drugs, etc.), but the leukocytic tests proved to be as conclusive and valuable as Chizhevskii's index and Piccardi's chemical tests. The data at our disposal were collected in different regions of both hemispheres, from the equator to the poles. The total number of observations reaches several hundreds of thousands (more than 150,000 tests having been performed at the town of Sochi alone). Examinations were conducted by hematologists of the Sochi Branch of the All-Union Scientific Society of Laboratory Physicians, and by our associates who often worked thousands of kilometers from Sochi.

Since the leukocytic tests of solar activity indicate the frequency of functional leukopenia and relative lymphocytosis in percentages, the actual

data make it possible to calculate the significant differences between individual groups and between the available indexes using the correlation coefficient.

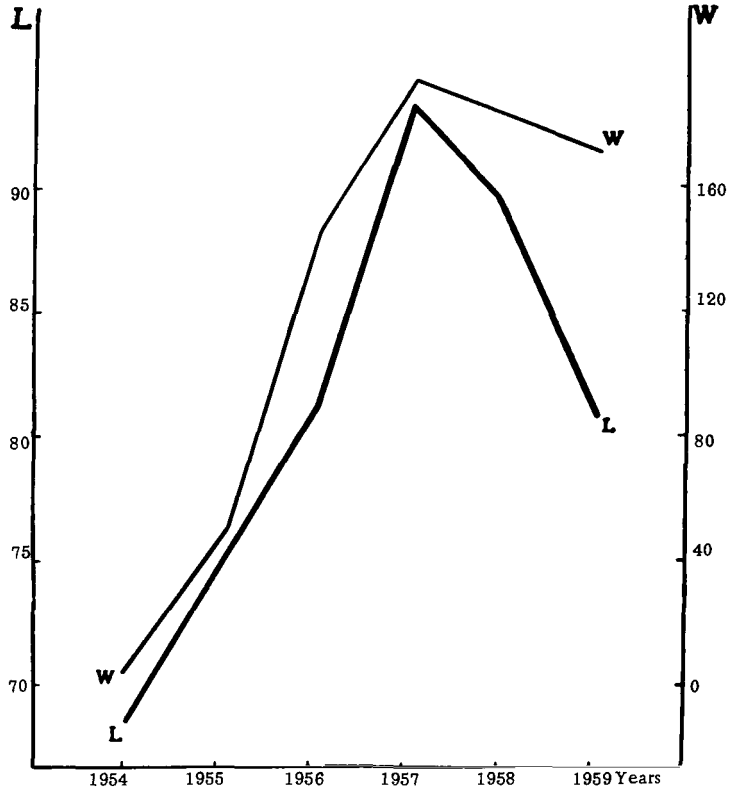


FIGURE 1. Variability of functional leukopenia and relative lymphocytosis correlated with variations in solar activity (90,000 observations).

Most observations were peformed on people in sanatoria, boarding houses, and rest homes located at different latitudinal and longitudinal sites in the USSR. Having established the pattern of fluctuations in the incidence of functional leukopenia and relative lymphocytosis in the Soviet subtropics and the Far North, the Baltic coast and the Pacific, and the Ukraine and Siberia, we decided to extend the range of our observations, and at present we have at our disposal data collected from laboratories of four continents. The data received are of utmost scientific value owing to their scope as well as to their wide geographical distribution. These data formed the basis of our investigations, one section of which deals with the leukocytic tests of solar activity.

Blood samples were always taken under the same conditions: in the morning, on an empty stomach, and in a sitting position so as to exclude the effect of food intake, physical stress, change of posture, etc.

Although we strove to exclude all usual factors causing functional leukopenia or relative lymphocytosis, some of the investigated subjects might have had leukopenia and lymphcytosis as a result of some disease, drug, or other causes; however, they were too few to affect the results of our tests, since we excluded data obtained from hospitals and clinics, although people who are sick react to variations of solar radiation in the same way as healthy people.

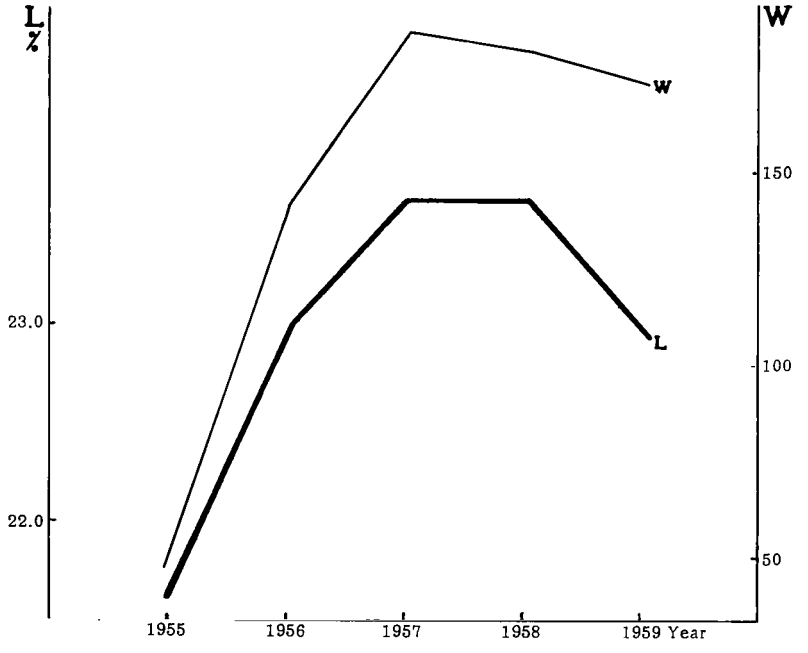


FIGURE 2. Functional leukopenia (L) in tuberculosis patients synchronized with the corresponding sunspot number (W) for the period 1955–1959.

As an example, we reproduce the results obtained by our associate, N. L. Glushitskaya, which clearly show leukopenia to be synchronized with the corresponding sunspot number in tuberculosis patients during the current 11-year solar cycle (Figure 2).

The progressive decrease in the number of leukocytes accompanied with a relative lymphocytosis in the blood of healthy people has been reported recently. As a result, numerous articles have appeared in medical periodicals, proposing a revision of the existing norms both for practical purposes and for special work in scientific research institutes.

Such a downward trend from the norm was observed for the first time at the end of World War I, when the incidence of relative lymphocytosis and of functional leukopenia increased, although the latter was not as pronounced as it has been in recent years. This phenomenon was designated "war lymphocytosis" (Kriegslymphocytose) by Klineberger. In those years, 1917–1918, there was a maximum of solar activity, although the

peak of the maximum was considerably lower than in the years 1957–1958, when the 11-year maximum coincided with the secular one.

In the 1920's the increased incidence of lymphocytosis was explained by nutritional changes. In those years, Eigenson's second basic solar index $\bar{a}$ had two peaks, indicating the mean intensity of solar phenomena and reflecting the intensity of geoactive corpuscular radiation; one peak occurred during World War I, and the other in the period of postwar famine. The authors of the 1920's, unaware of Eigenson's index $\bar{a}$ which was discovered in 1940, regarded the increase in lymphocytosis as a corollary of war and famine. At present there is neither war nor famine, yet the incidence and severity of relative lymphocytosis have not only exceeded that recorded in the 1920's but have continually increased in phase with the increase in the W index (sunspot number).

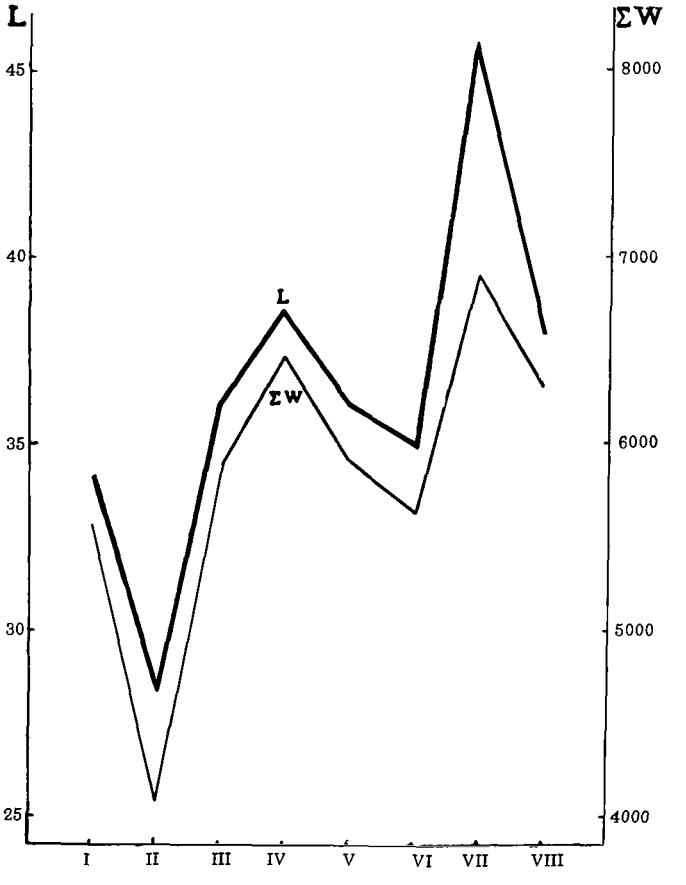


FIGURE 3. Variations in the incidence of relative lumphocytosis (L) and of the solar index Σw in 1957 (based on 14,100 tests performed at nine sanatoria at Sochi).

When correlating the fluctuations of leukocytic tests with those in solar activity we should bear in mind that fluctuations of solar indexes may be expressed by very large numbers, although there are known "ceiling" figures. The sunspot maximum recorded within the last 200 years occurred in 1957 (W = 189.9), and the minimum in 1913 (W = 1). Clearly, there cannot be variations of such wide amplitude in the blood system. Just as the temperature of the human body fluctuates within certain limits so does the incidence of functional leukopenia and lymphocytosis have a maximum and minimum. The maximum "C" of the leukocytic test was recorded in the same year as the sunspot maximum — 1957 — when it reached 95.5% (M. M. Levushkina, Sochi).

The leukocytic tests of solar activity distinctly revealed the variation with time of the incidence of functional leukopenia and relative lymphocytosis. This variation appeared to be in phase with the variations of solar activity (Figure 3).

According to our data the cyclic fluctuations of the leukocyte count is independent of meteorological factors. No noticeable changes could be detected in the frequency curve of leukopenia and lymphocytosis with the change of weather from cold and rainy to hot and dry. The seasonal dynamics fully reflected the Corti effect.* From the data collected at Sochi in 1956, leukopenia was found to be 13.8% during the winter and summer periods, and 16.8% during the spring and autumn periods. In 1957, at the same place, the incidence of leukopenia was 6.1% in winter, and 24% in spring, while leukocyte counts lower than 4000/mm^3 occurred in 0.2% of the cases in winter, and in 4.5% in spring.

With the passage of the maximum solar activity, the leukocyte counts show a gradual return to normal. However, since this was the maximum of the secular cycle, low leukocyte counts might be recorded in healthy people for a few more years.

In the middle latitudes leukocyte counts lower than 3000/mm^3 scarcely occurred in 1960, whereas in the Arctic regions there are still many healthy people with such counts. This biological test confirms the heliogeophysical principle that the effects of cosmic radiation are increasingly more pronounced toward the poles.

Determination and analysis of the effects of solar activity on the blood profile require a fundamental knowledge of the latest heliogeophysical achievements. Several observations led us to conclude that the blood is not affected directly by the sunspots but by certain solar phenomena (designated by Chizhevskii as Z-radiation), which are associated with the appearance and development of sunspots.

An example of coincident curves is provided by the leukocytic test "B," according to the results of 14,100 tests performed in 1957 in nine sanatoria of the Sochi area. The correlation in the annual variation of the leukocytic test "A" is clearly illustrated by the findings of our associates Z. A. Sencheshcheva and L. Ya. Krikovtsova, and is summarized in the curves of the leukocyte counts and solar activity, during the 1955–1959 period (Figure 5).

As mentioned above, a similar pattern was obtained by Glushitskaya at a tuberculosis clinic in Sochi during the 1955–1959 period. Hence, we may conclude that the blood of tuberculosis patients reacts to variations in solar

* In spring and fall the Earth is projected on the relatively more active latitudes of the Sun; hence, conditions are more favorable for it to be irradiated by the geoactive solar radiations than in summer and winter.

activity just as the blood of healthy subjects, irrespective of the pathological process affecting the number of leukocytes (see Figure 2).

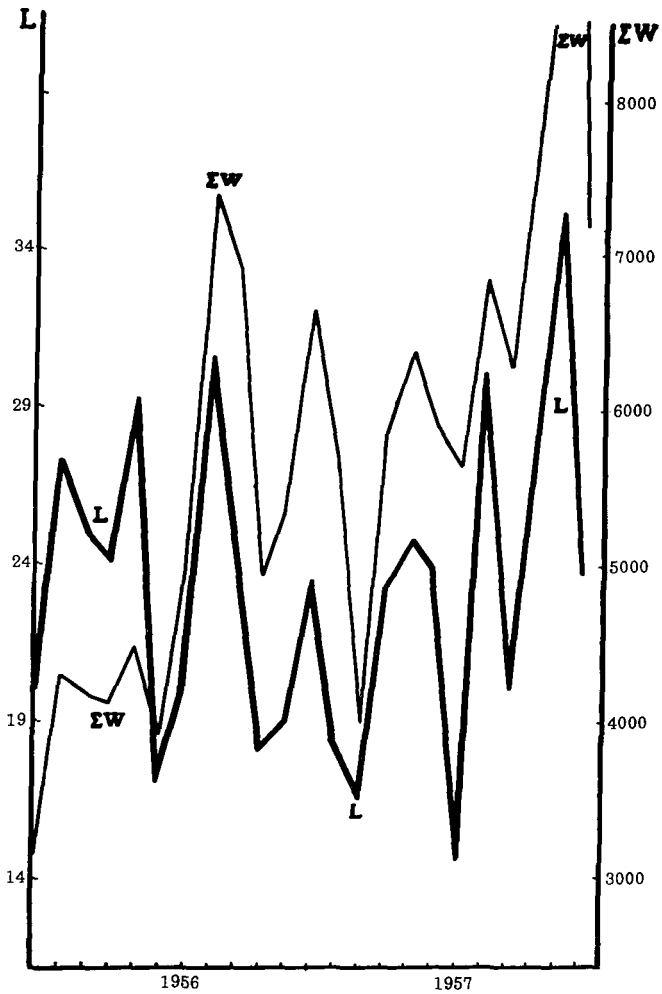


FIGURE 4. Incidence of leukopenia (L) synchronized with the solar index Σw at the peak of the secular cycle (1956–1957).

Considerable interest is also aroused by our observation that the curve of leukocytic tests began to rise earlier than the sunspot curve at the beginning of the current 11-year cycle. We are inclined to assume that this was caused by the enhanced activity of the excited areas* on the Sun, since the minimum of the current 11-year cycle occurred near the peak of the

* These are the M regions, or active longitudes representing the solar foci of magnetic disturbances.

secular cycle. Verification of this assumption will be possible in a few years, at the time of the next 11-year minimum. In the opinion of several heliogeophysicists this phenomenon merits attention (Figure 6).

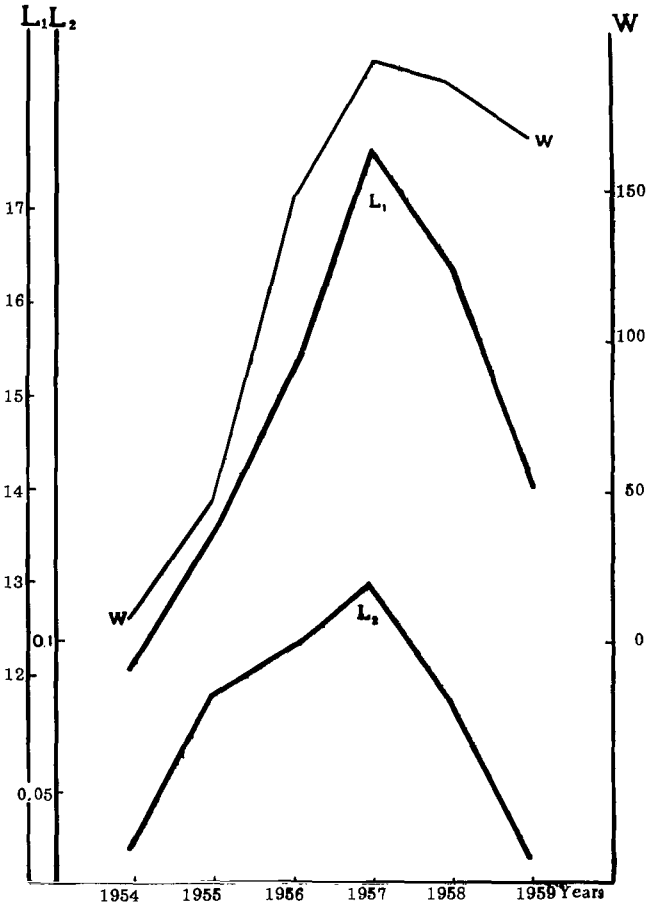


FIGURE 5. Percentage of functional leukopenia (L) synchronous with the sunspot number in the 1954–1959 period (according to Senchishcheva and Krikovtsova; 28,492 tests at Khosta): L_1–% of leukopenia with counts lower than 5000/mm^3; L_2–with counts lower than 3000/mm^3.

We cannot prevent the occurrence of magnetic storms nor sunspots, nor the passing of electromagnetic waves through the walls of our laboratories and ourselves. However, our studies are instrumental in recording the effects of these factors on the human organism, and especially on the blood; in correctly interpreting the deviations observed in several physiological processes; and in certain instances, in preventing their injurious influence by prophylactic measures.

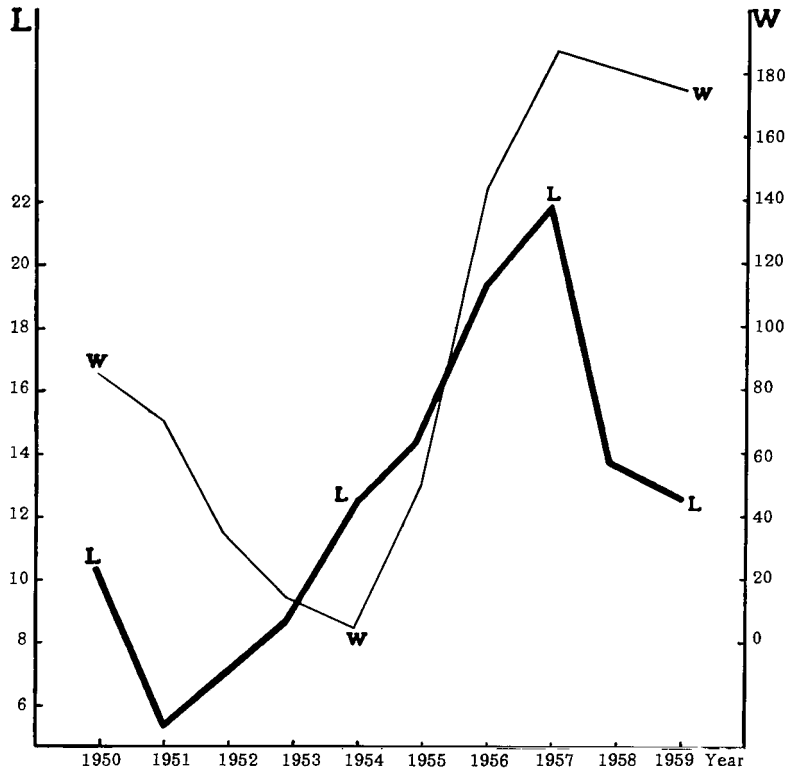


FIGURE 6. Rise of leukopenia preceding that of the sunspot number in the period of minimum W (according to data obtained at Sochi).

As mentioned earlier, the effect on the human organism of the chromospheric flares is of particular interest. These flares are sudden outbursts of colossal energy on the Sun, that reach and affect the Earth quite visibly. When viewed with a spectrohelioscope, an intense flare is perhaps the most striking spectacle in the entire sky, when part of the solar disk, sometimes exceeding 25 billion km^2, suddenly flares up with a blinding brilliance. The flares occur mostly in the central regions of sunspot groups, seldom away from them. Some sunspots may give rise to 30–40 flares during one crossing of the disk, while others, though of equal area, may generate only one flare if any. According to their properties three classes of flares are distinguished, from 1 (lowest intensities) to 3 (highest intensities). The human organism is affected by flares of the second and third class.

The flares not only radiate light, but also eject large quantities of solar matter, and when such a flare occurs near the edge of the solar disk it resembles an artesian fountain throwing jets of matter to heights exceeding 500,000 km at tremendous velocities.

The flares emit two types of radiation: electromagnetic waves, and corpuscular streams. The waves advance with the velocity of light and

affect the Earth simultaneously with the flare (within 8.5 minutes of their onset), whereas the solar corpuscles lag behind according to their different velocities resulting in the delayed effect. According to A. I. Ol', the particles ejected at velocities exceeding 1000 km/sec require more than two days to reach the Earth's surface.

The simultaneous effects include magnetic crochets (recorded on magnetograms), fading in short radio waves (familiar to all radio listeners), sudden intensification of atmospherics (radio disturbances), etc. The flare itself is a radio transmitter and its radio waves reach the Earth at the same time as the visible and ultraviolet radiations. The delayed effects include magnetic storms and polar auroras.

The four largest flares that occurred during the 20-year period since the beginning of continuous recording of cosmic rays produced sudden rises in the intensity of cosmic rays, that were especially pronounced in February and August 1956, and clearly reflected in the blood profile.

Our observations were conducted on the regular blood elements. The most sensitive to the effects of chromospheric flares seemed to be the leukocytes, especially the neutrophils whose number suddenly dropped, causing leukopenia and relative lymphocytosis.

With the passage of very large sunspot groups in February 1956, an intense flare was observed, accompanied with intense streams of cosmic rays. It was emphasized by several scientists that the scale of the February flare surpassed ordinary astronomical events. It drew the attention of many specialists, particularly those engaged in the study of cosmic rays.

Let us now examine the reaction of the blood to this tremendous solar flare. From the large amount of available data we selected those obtained by two laboratories situated in very remote regions (Khosta, in the Soviet subtropics, and Talaya, in the Soviet Northeast).

In January 1956, according to the data supplied by Senchishcheva (from a sanatorium at Khosta), the incidence of functional leukopenia (leukocyte counts lower than 5000/mm^3) was 14.5%. In February of the same year, after the flare, it doubled to 28.8%, then decreased to 13.3% in March, in July to 11.7%, and in October to 11.1%.

According to the data supplied by Ostroukhova (sanatorium at Talaya), the incidence of leukopenia was 8.4% in January, increasing to 19.1%, more than double, in February. In March it was 23.2%, 12.7% in July, and 12.6% in October.

The striking correlation of these data merits special attention. Statistical analysis of the data (calculation of mean errors, and determination of significance) confirmed our conclusions. The difference of the relative values exceeded the mean error of the difference by a factor of 5.24 at Khosta (January–February), and of 3.6 at Talaya (January–February). Approximately the same relationships were also maintained during the following months. The rather slight difference between the percentage variations in Khosta and those in Talaya were explained by the geographical latitude. The nearer to the poles, the more pronounced the effects of corpuscular radiation.

In the following table the gradual areal decrease of the above-mentioned sunspots was recorded over a period of three months by M. M. Gnevyshev and R. S. Gnevysheva (Mountain Astronomical Station of the Central

Astronomical Observatory of the Academy of Sciences of the USSR at Kislovodsk). We have included the data of the corresponding changes in the leukocytic test of solar activity (functional leukopenia and relative lymphocytosis as reported by M. M. Levushkina from "10 let Oktyabrya" sanatorium at Sochi).

Date	Area of sunspots in the active region while passing through the central meridian	Leukocytic test
21 Jan	1774 m.s.h.	91.7
17 Feb	3554 m.s.h.	98.8
16 Mar	1655 m.s.h.	97.0
13 Apr	901 m.s.h.	92.2

The second intense chromospheric flare occurred in August 1956. The Crimean Astrophysical Observatory reported that this was one of the most intense flares in 1956 with respect to its impact on the Earth's ionosphere and magnetic field.

From the laboratory reports at Sochi the leukocytic test of solar activity for the year 1956 reached the highest peak in August.

In the following table the synchronous monthly variations of the solar index and the leukocytic test of solar activity, as recorded by M. M. Levushkina, are summarized.

Month in 1956	Solar index	Leukocytic test	Month in 1956	Solar index	Leukocytic test
Jan	2217	91.7	July	5003	99.1
Feb	4328	98.8	Aug	7458	103.3
Mar	4274	97.0			
Apr	4211	92.2	Sept	6884	85.8
May	4651	94.0	Oct	4995	58.1
June	3956	85.3	Nov	5412	76.1

As evident from the data summarized in this table and in Figure 7, the leukocytic test of solar activity rose significantly in February and August, after the intense chromospheric flares.

As with any new problem, the effect of solar activity on the human body should be cautiously approached, and examined strictly in its own right so as not to compromise this topical and promising concept.

The large number of works published on this subject by scientists in various fields of research amply demonstrate the significance attached to it; their conclusions compel us to acknowledge the undoubted influence of solar activity on a whole range of physiological and pathological processes. These results call for continuation and expansion of this research by collecting data and producing additional evidence of the manifestations of these phenomena, since the newness of the subject has so far allowed only

the recording of several outstanding facts, the formulation of working hypotheses, etc.

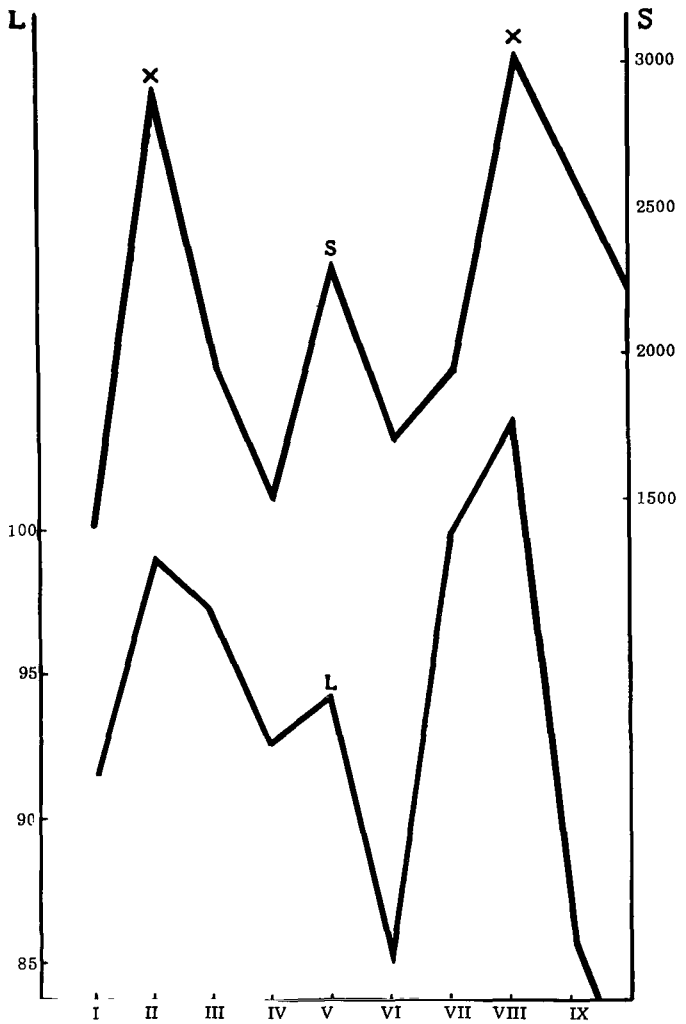


FIGURE 7. Correlation of solar index and leukocytic test from data of M. M. Levushkina (Sochi), in 1956; x-axis—months; y-axis—solar index S (area of sunspots); L—Leukocytic test (percentage incidence of functional leukopenia and relative lymphocytosis); X—powerful chromospheric flares.

It is regrettable that the medieval geocentric notion of the universe that reigned before the time of Copernicus still permeates many scientific principles. We often regard the life processes on Earth as being isolated, limited by the terrestrial boundaries, and linked exclusively to their

immediate environment. Thus, we ignore cosmic relationships and the tremendous influence on the biosphere of the cosmic factors, among which the most influential and powerful, with respect to the essence of life, is the Sun, and particularly solar activity.

This activity is expressed by different indexes. The W index (Wolf number) is mostly used by scientists, and indicates the relative number of sunspots; in the medical field, however, our experience has shown that the S index (designating the area of sunspots) is more convenient and accurrate since the organism is more affected by a small number of sunspots extending over a large area than by a large number of sunspots covering a small area.

Another advantage of the S index is evident from the separate recordings of the sunspot areas in each solar hemisphere. This is very important if we recall that every six months another hemisphere of the Sun is turned toward the Earth. Thus, from 4 June to 8 December the Earth traverses part of its orbit while facing the northern solar hemisphere, and is possibly subjected to the effects of its radiation; from 8 December to 4 June the Earth rotates along its orbit while facing the southern solar hemisphere, and the effect of the latter may prevail for this part of the year. In contrast, the W index is calculated for the entire solar disk. The area of sunspot groups in an 11-year cycle gives rise to a single-peak cycle, in one solar hemisphere, while in the opposite hemisphere a double-peaked cycle develops. Thus, the S index reflects the varied and complex character of areal development of the sunspot groups in the solar hemispheres, whereas these characteristics of the cycle are not taken into account by the W index (A. Ya. Bezrukova).

We must also mention the photospheric index of the area of solar flocculi, which, similar to the sunspots, vary cyclically; their minimum variation coincides with the minimum of sunspot formation.

Another promising path of research in our field is the comparison of certain physiological and pathological processes with variations of the index of intensity of the coronal line $\lambda = 6374$ Å, which indicates the maximum intensity during the cycle minimum.

The intensified activity of magnetic regions on the Sun during the minimum periods of solar cycles has a pronounced influence on the blood system. Since our data on the ultraviolet and corpuscular indexes are inadequate thus far, any comparison with them should be made with great caution.

Bazrukova's hypothesis that different solar indexes are representative during the various phases of the 11-year cycle has been confirmed by our findings.

Unfortunately we cannot apply G. Piccardi's method under our clinical conditions since we deal with the human organism rather than colloid solutions. At this stage in our study of the problem we are limited to the statistical method alone, which is not less accurate than the experimental method when all conditions required for a valid solution of the problem are met as in experimental work.

Primary attention should be paid to the selection of the object of observation, which is sometimes rather difficult. We have excluded children and old people from our survey because their blood profiles reflect age characteristics which are subject to significant fluctuations.

A correct analysis of the experimental data should take into account all factors that might affect the process under investigation. Thus, we were frequently compelled to discontinue our observations because of changes in the blood profile induced by the onset of epidemics, such as influenza, which causes leukopenia and relative lymphocytosis, etc.

In addition to the accuracy of calculations, the statistical techniques must be correctly applied in order to prevent erroneous interpretation of the experimental data.

Random sampling was generally adopted in order to minimize prejudice and subjective factors.

Unfortunately, these elementary requirements are not always met and frequently masses of data must remain unprocessed solely because the necessary statistical conditions have not been fulfilled.

Hence, caution and thoroughness are evidently required in order to determine the influence of solar activity on the human organism, for only sound and lucid statistical analyses may prevent errors in the correlating of certain human physiological and pathological processes with variations of solar activity.

REFERENCES

Publications in Russian

BEZRUKOVA, A. Ya.— Trudy Laboratorii Ozerovedeniya AN SSSR, Vol. 3. 1954.

BEZRUKOVA, A. Ya.— Solnechnye Dannye AN SSSR, No. 7. 1960.

CHIZHEVSKII, A. L. Epidemicheskie katastrofy (Catastrophic Epidemics), pp. 1–172. Moskva. 1930.

EIGENSON, M. S. Ocherki fiziko-geograficheskikh proyavlenii solnechnoi aktivnosti (Physicogeographic Manifestations of Solar Activity). Lvov. 1957.

GNEVYSHEV, M. N. and R. S. GNEVYSHEVA.— Solnechnye Dannye AN SSSR, No. 2. 1956.

OHL (OL'), A. I.— Ibid., 79, No. 1. 1954.

SENCHISHCHEVA, Z. A. and L. Ya. KRIKOVTSOVA.— Ibid., No. 3. 1960.

SHUL'TS, N. A.— Priroda, 92, No. 6. AN SSSR. 1959.

SHUL'TS, N. A.— Problemy gematologii i perelivaniya krovi, 41, No. 7. 1959.

SHUL'TS, N. A.— Laboratornoe Delo, 36, No. 2. 1960.

SHUL'TS, N. A.— Solnechnye Dannye AN SSSR, No. 7. 1960.

SHUL'TS, N. A.— Ibid., No. 9. 1960.

SHUL'TS, N. A. Stenogramma doklada na Vsesoyuznom mezhduvedomstvennom soveshchanii Akademii nauk SSSR, posvyashchennom probleme "Solntse–troposfera" (Stenogram of a Lecture Delivered at the All-Union Interdepartmental Symposium of the Academy of Sciences of the USSR, Devoted to the Problem Sun–Troposphere), Leningrad. 1960.

SHCHERBINOVSKII, N. S. Osnovnye zakonomernosti massovykh razmnozhenii pustynnoi saranchi i migratsii ee stai (Main Patterns of Mass Proliferations of the Desert Locust Schistocerca and the Migrations of Its Swarms). Moskva. 1958.
SLONIM, Yu. M. — Solnechnye Dannye AN SSSR, No. 3. 1959.
Solnechnye dannye AN SSSR, 54, No. 5. 1952.

Publications in Other Languages

BACH, E. and L. SCHLUCK. — Zentralblatt f. Gynäkologie, 66, pp. 196–221. 1942.
BECKER, U. — Archiv Met., Geophys., Biokliomat., B. 6, pp. 511–516. 1955.
BERG, H. Probleme der Kosmischen Physik. — Leipzig, B. XXX. 1957.
BERG, H. — Med. -Met. Hefte, 5, pp. 1–17. 1951.
BERG, H. — Symposium internat. Bruxelles, p. 160. 1960.
BERG, H. — Bioklimat. Beibl., 10, pp. 130–133. 1943.
BURKARD, P. — Archiv Met., Geophys., Bioklimat., B. 6, pp. 506–510. 1955.
CAROLI, G. — Med. -Met. Hefte, 4, pp. 12–26. 1950.
DÜLL, T. and B. VIRCHOVS. — Archiv, 292. 1934.
ELLISON, M. A. The Sun and Its Influence. London. 1955.
FILK, H. Uber eine nephelometrische Methode zur Bestimmung der Serumeiweisskörper. 1950.
GIORDANO, A. — Geofisica e Meteorologia, Vol. 8, Nos. 3–4. 1960.
PICCARDI, G. —Wiener Mediz. Wochenschrift, No. 47. 1956.
PICCARDI, G. — Wiener Mediz. Wochenschrift, No. 6. 1958.
PICCARDI, G. — Rendiconti dell'Academia Nazionale dei Lincei, Ser. VII, Vol. XXV, f. 6. 1958.
PICCARDI, G. L'influence des phénomènes terrestres, solaires et cosmiques sur les reactions physico-chimiques et biologiques. Bruxelles. 1956.
PICCARDI, G. Les testes chimiques. —Sympos. international. Bruxelles. 1960.
RUDDER, B. de. Grundriss einer Meteorobiologie des Menschen. Berlin. 1952,
SCHULZ, N. A. — Geofisica e Meteorologia, Vol. 8, Nos. 5–6. 1960.
SCHULZ, N. A. — Toulouse Médicale, No. 10. 1960.
SCHULZ, N. A. — Leukozyten— Teste der Sonnenaktivität. — Folia haelmatologica, 79/4. 1962.
Sunspot and Geomagnetic-Storm Data Derived from Greenwich Observations 1874–1954. London. 1955.
Symposium internat. sur les relations entre phénomènes solaires et terrestres en chimie, physique et en biologie. Bruxelles. 1960.
TAKATA, M. and T. MURAZUGI. — Bioklimat. Beibl., 8. 1941:
TCHIJEVSKY, A. L. Epidémies et les perturbations electromagnetiques du milieu extérieur. — Hippocrate. Paris. 1938.
Zeitschr. Astrophys., 35, No. 1, pp. 1–9.

N.S. Shcherbinovskii

THE RHYTHMS OF PROLIFIC BREEDING OF ORGANISMS DETERMINED BY CYCLIC SOLAR ACTIVITY

The development and entire life of any organism— from microscopic bacteria to the higher animals— depends not only upon the immediate environment, which at the present level of science and technology can be fairly easily modified in the desired direction, but also upon the solar radiation which supplies our planet with light and heat and as a result of which life has emerged and developed, and is sustained to this day on Earth.

The classical research of K. A. Timiryazev has revealed the pattern of photosynthesis whereby the chlorophyll in plants entraps and converts the energy of light or of solar radiation into chemical energy in the organic substances. However, beyond the limits of visible light lies the region of invisible radiation, especially that of the short ultraviolet (UV) rays. This radiation is endowed with high biological and chemical activity which influences not only the course of certain chemical reactions (including the state of colloid solutions), but also the formation of proteins. These natural processes are still not clearly understood, and should be thoroughly investigated since they directly affect the development of progressive agriculture.

Ultraviolet radiation varies markedly during the 11-year cycle of solar activity, causing significant changes in the energy balance of the ionosphere, stratosphere, and finally the Earth's surface. The Sun has a tremendous effect on all processes wherever they take place, from the highest layers of the ionosphere to the troposphere. The uneven time and spatial distribution of solar energy in the gaseous envelope and over the surface results in severe frosts in the Antarctica (−87°C), while our thermometer recorded +82.2°C on the sands and gray soils of tropical deserts in Asia.

Solar radiation determines displacement of enormous air masses on our planet, and also variations in barometric pressure. It governs the direction and volume of ocean currents, and the evaporation and transport of millions of cubic kilometers of water, thus determining the weather on all continents. It may variously give rise to violent storms that carry away the fertile topsoil, prolonged droughts that nearly destroy entire harvests, and torrential rains (considerably heavier than the normal atmospheric precipitation) that inundate extensive areas. Obviously, such extreme fluctuations of weather conditions must affect the development of vegetation, including crops, and the breeding of all organisms including agricultural pests.

In the interest of the national economy biologists and agronomists must focus their attention on the following:

1. The effect of solar radiation on the specific rhythm of proliferation of as many organisms as possible, especially of insect pests, and particularly of those insects that multiply periodically in great masses over extensive areas causing heavy damage to crops; and also the possibility of foreseeing the menace of such a population explosion of the insect pests by correlating it with the rhythm of solar activity.

2. The changes in the cellular microstructures of living organisms induced by internal and external factors, in order to recognize more clearly the pattern of development and multiplication of organisms, both harmful to and useful for agriculture.

It would be erroneous to assume that these two problems (especially the first) could only be studied by a narrow group of specialists in astronomy, climatology, and meteorology. Every biologist, agronomist, and any other agricultural specialist can and should observe and study the phenomena taking place in the surrounding environment in an endeavor not only to collect the necessary data, but also to analyze them and to draw the appropriate conclusions. Simple observations of the weather and of the mass reproduction of useful and harmful species conducted without the aid of instruments might prove to be of both scientific and practical value, provided they are recorded regularly over a period of many years.

Evidently, the solution of biological and agricultural problems will be achieved only by embarking on new untrodden paths of research. Occasionally, even remote branches of science will bring us nearer to understanding the laws of nature and to controlling them for the benefit of man.

KNOWLEDGE AND RECORDING OF THE SOLAR-ACTIVITY PATTERN FOR IMPROVED FORECASTING OF MASS REPRODUCTION AMONG HARMFUL SPECIES

The planned socialist economy demands that agriculture be administered strictly according to scientific principles. Agricultural pests cause tremendous damage assessed at 45 billion old rubles* per year. The necessity for a well-organized government system for the protection of plants is obvious. However, maximum control of pests and diseases of cultivated plants cannot be achieved, even with the best organization, unless it is based on a comprehensive and thorough knowledge of the patterns governing the development and proliferation of harmful organisms, and of the effect on these processes of environmental factors including solar radiation and the activities of man himself.

Together with the best methods of pest control one of the decisive factors in plant protection should be the forecast and warning of the appearance of the most dangerous mass pests such as locusts, grain moth, Eurygaster integriceps, and others, as well as certain species of rodents. The earlier the forecasts are made, and the more accurately defined the areas

* [Ten "old rubles" are equivalent to one "new" (currently used) ruble.]

of potential mass outbreak of each plant pest, as well as the intensity of the expected epiphyte, the more effective will be the measures adopted for the crop protection.

The cyclic variability of the Sun has long been known /1/. Without discussing the complex causes of the Sun's physical instability (resulting from the release of nuclear energy), we should note that the cycle of 11.4 years (usually referred to simply as the 11-year cycle) has been well established, after having been followed accurately over more than three centuries. In addition there is another known cycle of solar activity of 22–23 years. According to their magnetic properties, the 11-year solar variations could justly be considered half-cycles of the 22–23-year cycle. There is also the 36-year cycle (average duration) which was established by E. Brückner. Many scientists have confirmed the continued manifestations of the 36-year cycle in the course of the past millenia.

The fullest scientific data are available for the 11-year and the double [22–23-year] cycles of solar activity. The most easily detected signs of increasing solar activity are the sunspots, which are actually giant vortices, or cyclones, consisting of fluxes of electrically charged particles moving at tremendous velocities.

In the years of minimum solar activity the solar disk is devoid of sunspots for several months, and there is also an attenuation in other signs of its activity. Increasing activity is accompanied with an increase in the number of spots which appear in groups, attaining enormous dimensions. Such sunspots have been thoroughly investigated and described in detail.

In 1947, the year of maximum activity of the previous 11-year cycle, there appeared a group of sunspots on 7 April which extended over an area of 180 billion km^2! The spots grew rapidly starting early in February, reached a maximum in April, and disappeared in 11 May.

Such sunspots are clearly visible on the Sun when viewed through a smoked glass. Naturalists have recorded sunspots since the construction of the first telescope in 1610. However, more accurate records (monthly) have been available from 1749. Since sunspots reflect solar activity, Wolf numbers (W) were adopted as the index of this activity.

According to academician L. S. Berg /3/, "Solar activity has followed approximately the same 11-year cycle since most ancient times, i. e., throughout the past half billion years. Climatic cycles of several decades, such as those recorded in the last centuries, also occurred 500 million years ago." Berg maintained that layers deposited in southwestern Africa, approximately 500 million years ago, and similar deposits in the USA and Western Europe revealed the cycles of 11.4–11.5 years corresponding to the contemporary periodicity of sunspots.

Abundant data have also been collected by biologists engaged in studies of the life activities and development of algae, coral reefs and the development and migration of fish. According to Prof. P. Yu. Shmidt, the 11-year cycles were especially pronounced in cod, herring, and other fishes.

We shall briefly examine the rhythm of growth of corals as an indicator of the effect of solar cycles on aquatic life. Thorough investigations of the structure of calcareous formations of contemporary coral reefs as well as of those formed in other geological periods (Silurian, Devonian, Carboniferous), clearly revealed the regular alternation of comparatively large thin-walled elements with small, thick-walled ones. This thickness variation of the "coral tissue" is the result of seasonal and long-term

fluctuations of the temperature in the World Ocean. The rhythm of growth of the coral structures in the oceans correlates well with the general rhythm of solar activity, clearly demonstrated by the findings of V. B. Shostakovich /4, 5/, and in the alternating layers of silt deposits in the oceans, seas, and continental lakes of both hemispheres. At this point we must mention the pioneer in this field, Prof. F. N. Shvedov, who developed the concept of the influence of periodic solar activity upon life on Earth. By the end of the last century, Shvedov demonstrated an 11-year periodicity in the annual tree rings. He related this periodicity directly to fluctuations in atmospheric precipitation, thereby designating the trees as "drought chronicles" /6/.

It is seen that in the "water and Earth chronicles," the silt deposits at the bottom of oceans, the coral reefs, and many other sources prove that dead and living matter on our planet had reflected, in the course of hundreds of millions of years, the eternal rhythms of solar activity.

Entomologists are well aware of the rhythm of mass reproduction of locusts, especially of Schistocerca gregaria, for which our data show fifteen population explosions in the course of the past 160 years, i.e., as many as the number of 11-year cycles of solar activity for the same period of time.

A. V. Mitchener, professor of entomology at Winnipeg University (Canada) has written that mass outbreaks of four locust species have been reported from the prairie provinces at intervals of approximately 10 years, resulting in many millions of acres of damaged crops, and losses of many millions of dollars. Each cycle of mass reproduction lasts about five years, after which there is a period of "calmness" for another five years. This rhythm has been recorded since the year 1799 /8/.

Other findings were reported from America. Fierce, regular onslaughts of cotton leafworms were recorded in the cotton belt of the USA, every 21 or 22 years, since the 1770's. The pest ravaged the crops (in many states almost completely) for 2 or 3 years, and disappeared again for 18 or 19 years. The mass outbreaks were synchronous with the 22-year cycles of solar activity. Having established this fact, the American entomologists expected the oncomming outbreak of the parasite at the beginning of the 1950's. They prepared themselves to suppress this proliferation at its very beginning and succeeded in overcoming it by chemical means in the southern cotton-growing states.

This fact proves quite conclusively the possibility and expediency of using heliophysical data for predicting many years in advance the mass outbreaks of certain species of insect pests.

We may note that we predicted, 10 years in advance, outbreaks of this species, in Iran, Iraq, Arabia, India, and Pakistan on the basis of long-term studies of the biology and ecology of Schistocerca, started at the time of the massive locust invasion of Central Asia in 1929. The predictions were also based on all the available Soviet and foreign literature, and on the rhythmic fluctuations of precipitations in the zone of the subtropic deserts in Asia and Africa (peasants' keenness of observation and folklore recorded these rhythms long ago, since the times of the Pharaohs in ancient Egypt). Over a period of 30 years our forecasts have been confirmed with an accuracy of months.

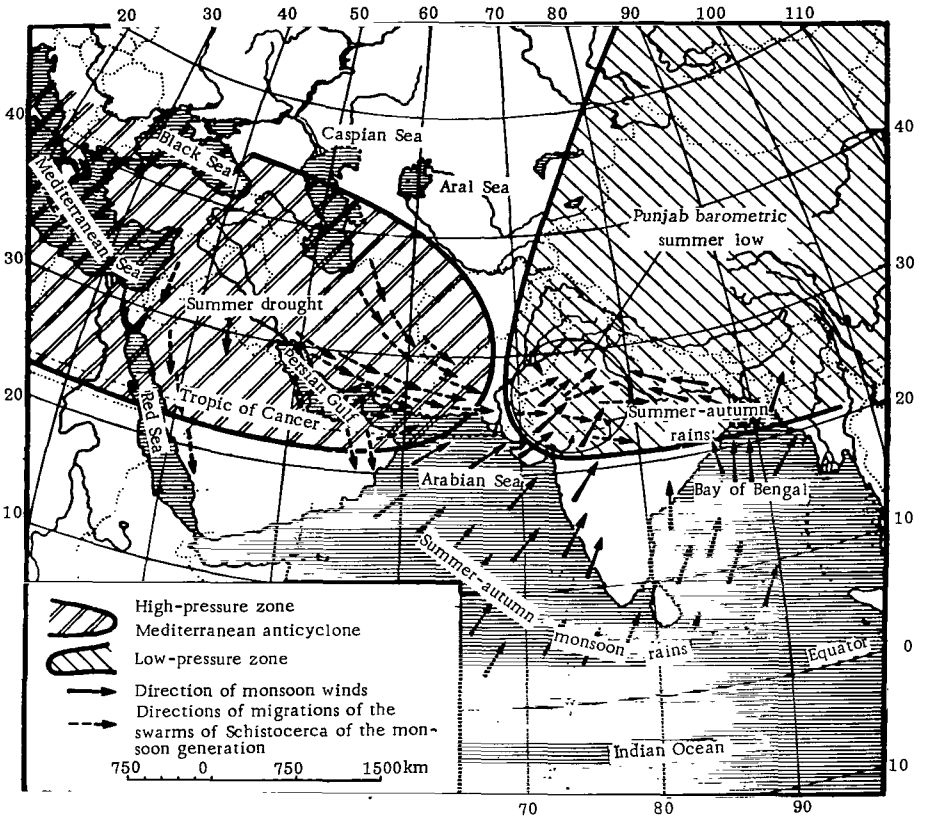


FIGURE 1. Summer migrations of Schistocerca to zones of Mediterranean winter precipitation at the end of the summer monsoon. The baric contour comprises the second half of October and the months of November, December, and January.

Let us now turn our attention to the vast territories of the northern regions of Kazakhstan and to West Siberia, where an unusually fierce mass outbreak of grain moth occurred in 1957. Neither the entomologists nor any of those concerned with agriculture expected this calamity. Although the onset of intensive proliferation of the grain moth was recorded in the previous year, the pest was almost forgotten owing to its suppressed state during the preceding 20 years. This parasite was never regarded by the agricultural workers as a dangerous pest, but suddenly, it spread with an unprecedented population explosion. We then started to study and summarize the available literature on previous outbreaks of the grain moth, searching, in particular, the archives of provincial "zemstvo"* offices and of other organizations including those in the area of the Urals. Thus, we learned of mass reproduction of the grain moth in these areas in the years 1885–1888, 1910–1912, 1935–1937, and 1956–1960, the latter of which involved millions of hectares of crops in the regions of northern Kazakhstan and partially in West Siberia. Between these devastating outbreaks of grain moths, moderate invasions were recorded every

* ["Zemstvos" were organs of limited rural self-government in pre-Revolutionary Russia.]

10–12 years involving more limited areas, and were also noticed in other regions of the USSR.

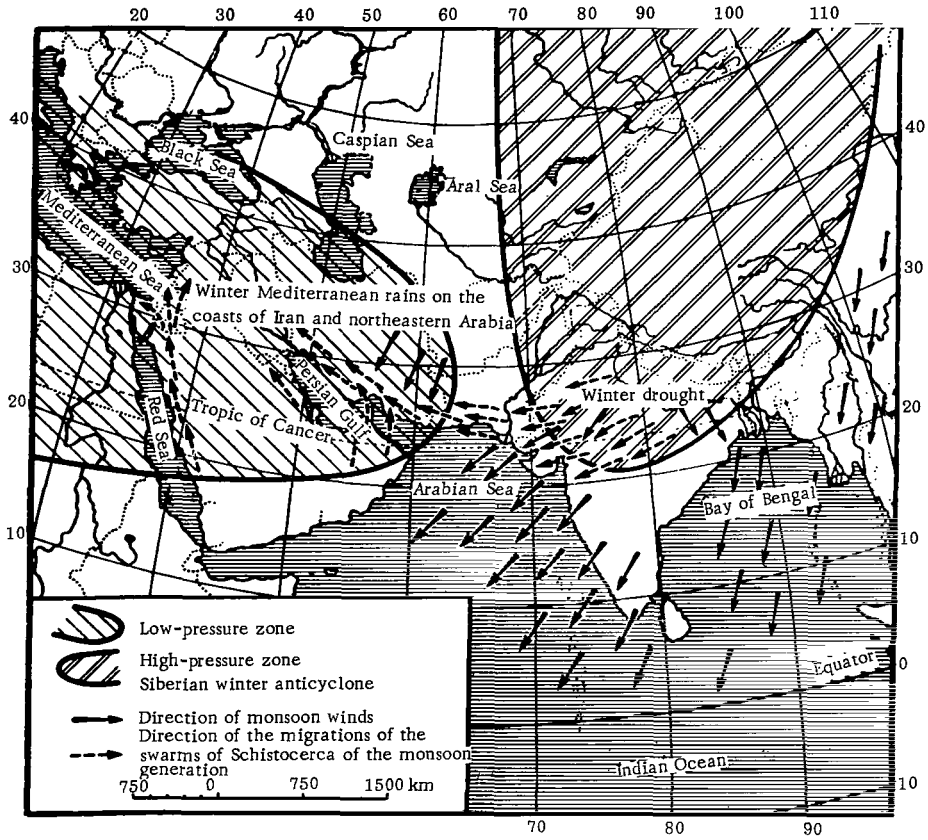


FIGURE 2. Winter migrations of Schistocerca swarms into the zone of monsoon rains. The baric contour comprises the months June, July, August, September, and the first half of October.

Many prominent entomologists attributed the mass outbreak of the grain moth in 1957–1959 to the start of extensive breaking up of virgin lands, and to the combines used for harvesting the crops, i. e., to anthropogenic factors rather than to changes in weather conditions in the given areas. We certainly acknowledge the potent effect of human activities on the dynamics of insect populations, but we categorically disagree with the statement that solar radiation has no effect whatever on the proliferation of insects. According to Ya. I. Chugunin, "Meteorological factors do not and cannot affect fluctuations of the gypsy-moth population."

Such antiscientific "theories" that nullify Michurin's basic biological principles concerning the effect of environment on the development of every organism, rather than promoting the development of our science, obstruct the way to our understanding the patterns existing in nature, and cause real damage to agriculture.

Objections should be voiced unequivocally against such a primitive, antiscientific comment on the role in nature of that unique source of energy,

the Sun, which exerts an incontestable, though very complex and often indirect influence over life on our planet. It induces changes in the atmospheric circulation, and hence in the weather conditions that govern insect breeding and the pathogenic microorganisms which attack them.

Immediate steps should be taken toward research performed jointly by biologists and heliophysicists. The relevant literature should be thoroughly read and the new criteria applied in order to evaluate the methods of forecasting mass outbreaks of crop pests.

It is regrettable that the majority of plant-protection experts ignore the wise statement made by one of the founders of Russian meteorology, P. I. Brounov /9/: "...The barometric conditions together with the Sun constitute the basis of all processes on Earth, the basis of all life on Earth... The barometric conditions govern the winds, and the Sun governs humidity, temperature, cloudiness, precipitation, etc., i. e., the entire intricate complex of phenomena that constitute climate, upon which depend the soil, the vegetation, and the animal world." These statements not only give us the right but also compel us to emphasize the necessity of "raising our eyes toward the Sun," so to speak, to direct our thoughts toward a full understanding of those cosmic patterns and inexhaustible sources of energy (solar, wave, and corpuscular) which influence the physical and biological processes on Earth, including the biochemical changes in the cells of living organisms.

Extremely valuable data were obtained during the recent International Geophysical Year and the following International Geophysical Cooperation. These years were specially selected because they included a period of solar maximum activity.

The Soviet space satellites ("sputniks") and altitude rockets equipped with modern instruments were used for investigating the highly complex processes occurring in the formerly inaccessible upper layers of the atmosphere. They revealed that extremely high-energy phenomena are generated in the ionosphere by the continuous invasion of solar radiations, including X-rays, ultraviolet and radio-frequency waves, as well as by innumerable material particles — corpuscles traveling at velocities ranging from a few thousand kilometers per second to those of the order of the speed of light.

Soviet space satellites and rockets discovered the hitherto unknown radiation "belts" surrounding the globe at different altitudes corresponding to the geomagnetic field. Depending on the intensity of solar activity magnificent polar auroras and magnetic storms are generated at high altitudes causing interruptions in radiocommunications.

Soviet scientists proved that solar energy affects the tropospheric circulation, and acts directly on the Earth's crust, on the flow of oceanic currents, and on all organic life.

There is no doubt that the periodic droughts reported by many Soviet scientists (L. S. Berg, V. R. Vil'yams, N. A. Maksimov, V. P. Mosolov, and others) are determined by the Sun. They studied drought periodicity in the vast areas of southern and southeastern USSR, where the yields of many crops had been extremely poor. Shnitnikov demonstrated that in Kazakhstan and West Siberia, where the grain moth multiplied periodically four times in the course of the last century, the rhythm of precipitation, temperature, and other meteorological parameters changed abruptly and

synchronously with the solar activity cycles, while the water level in lakes varied by more than 5 meters.

Geophysical science has corroborated that solar causes are responsible for variations in the water level of the Caspian Sea, the ice layer in the polar basin, the rate of influx of cold-air masses in the Arctic, the shifts of cyclone paths, etc.

Fluctuations of the water level recorded in more than one hundred lakes in Kazakhstan and Siberia in the last two centuries, and known to have taken place throughout many more centuries (according to historical data and excavations) display a periodicity of 20, 30–35, and 50 years, corresponding to the cycles of solar activity. The 11-year cycles were not as distinctly marked by variations in the lake levels, but they were clearly indicated in the steppes of northern Kazakhstan and West Siberia by mass outbreaks of the Karakurt (poisonous spiders). These could not pass unnoticed even by the local nomadic population because in years of mass appearance of these spiders man and beast died in large numbers of their poisonous bites.

The karakurts live in virgin steppes on the slopes of hills so that attempts at explaining their mass breeding by means of modern equipment seem rather naive, the more so as these proliferations were recorded more than a century ago. Two cycles have been established by Marikovskii in the mass outbreaks of the poisonous spiders in the steppes of Kazakhstan and West Siberia: one of 10–12 years, and the other of 20–25 years. These cycles can be traced since the 1830's to the present day /10/.

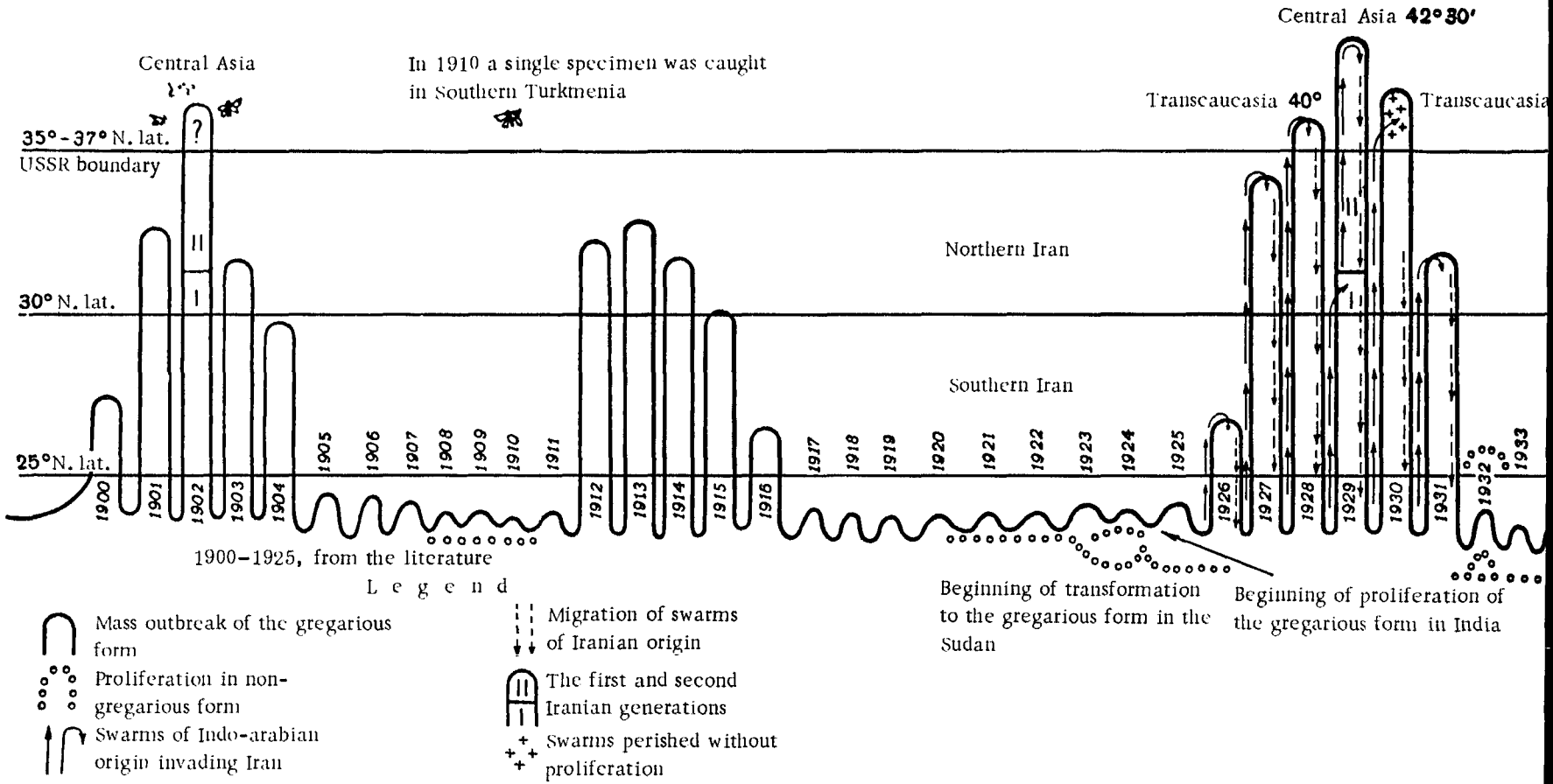
We have dwelt in some detail upon this geographical region because of the recent, unexpected outbreak of the grain moth over an area of seven million hectares.

In this connection it might be interesting to trace the observations recorded by people, not only in our time but also centuries and even millenia ago, of the aforementioned periodic fluctuations of the insect and spider populations caused by changes in weather conditions.

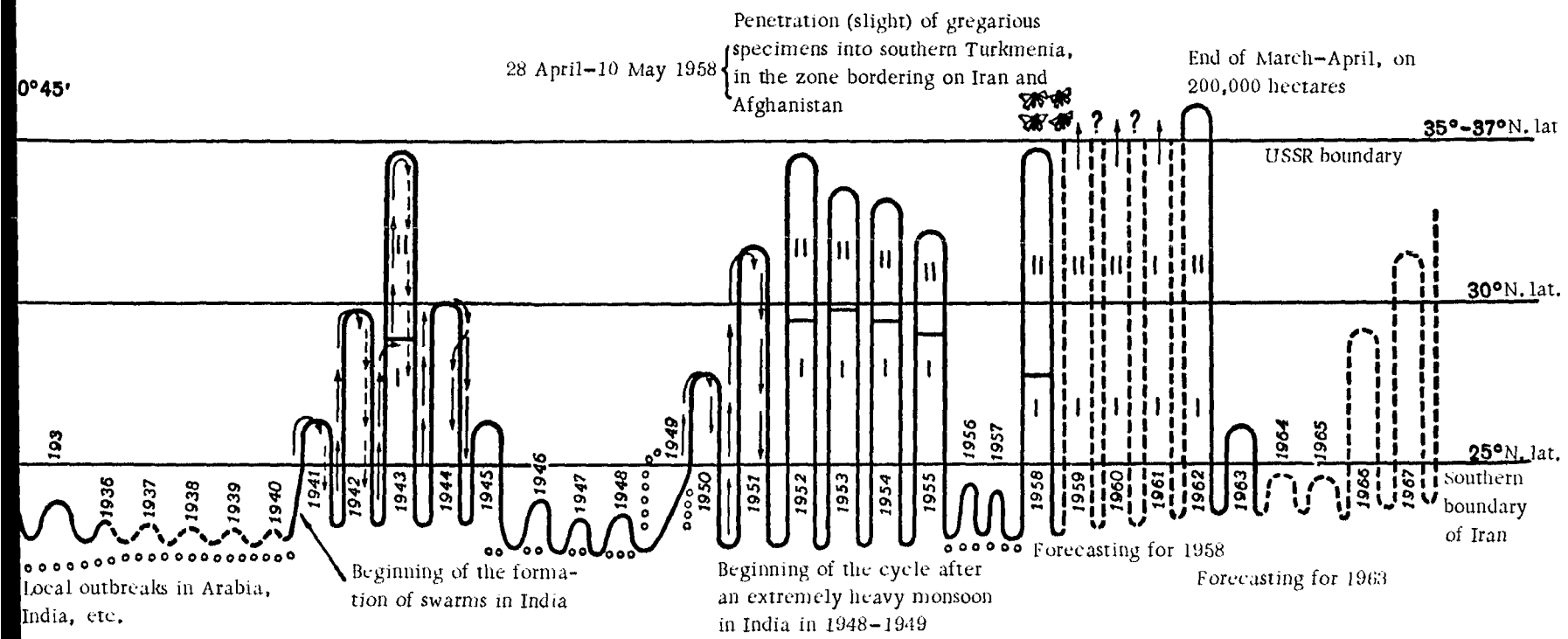
In ancient times, centuries before our chronology began, a 12-year calendar cycle was already being used by the Chinese, Mongolian, and Turkic peoples in the steppes and semideserts of East Asia /11/.

Why then did this ancient cyclic calendar, "mushel," extend over 12 years, with each year being designated by the name of a certain animal: cow, horse, ram, panther, hare, and even mouse and the mythological dragon? Historians and ethnographers have correctly assumed that this "mushel" must have been realistically related to the economics and way of life of the ancient nomads who had made the transition from hunting to nomadic animal husbandry. Their life was based on their livestock; the pastures were limitless and inexhaustable, but the weather, the precipitation in winter and summer, and the temperature were extremely unstable. At times, the herbage was scorched by searing droughts by as early as spring, and at other times the ground was covered with an ice crust during the severe winters. Masses of animals, deprived of any forage, died of starvation. The local word for mass death of starved animals was "dzhut."

Centuries ago the nomads noted that "dzhuts" of exceptional severity occurred at intervals of 11 and 12 years. Thus arose the idea of a 12-year-cycle animal calendar. The most difficult year was that of the hare, "koyan," with the most destructive "koyans" occurring every 36 years. They



Graph of the cyclic mass reproduction of the locust Schistocerca and invasions of the USSR by its swarms, in the twentieth century.


0°45'
28 April–10 May 1958
Penetration (slight) of gregarious specimens into southern Turkmenia, in the zone bordering on Iran and Afghanistan
End of March–April, on 200,000 hectares
35°–37°N. lat
USSR boundary
30°N. lat.
25°N. lat.
Southern boundary of Iran
193
1936
1937
1938
1939
1940
1941
1942
1943
1944
1945
1946
1947
1948
1949
1950
1951
1952
1953
1954
1955
1956
1957
1958
1959
1960
1961
1962
1963
1964
1965
1966
1967
Local outbreaks in Arabia, India, etc.
Beginning of the formation of swarms in India
Beginning of the cycle after an extremely heavy monsoon in India in 1948–1949
Forecasting for 1958
Forecasting for 1963

1419/338—339

were known locally as "ul'kum-dzhut." In such years the nomads lost as many as 60% of their horses, half of their sheep, 97% of their goats, and 50% of their camels. On the whole, in the "dzhut" years millions of domestic animals perished and many nomad camps lost more than half their population. Wild animals and fowls of the steppe likewise perished during the "ul'kum-dzhuts" (wild asses, saigas, gazelles, wild sheep, bustards, partridges, pheasants, foxes, etc.), and the famished population was forced to fish the steppe lakes. This may possibly be the reason why one of the years in the "mushel" calendar is dedicated to fish.

Naturally, such extreme fluctuations in weather conditions, now scientifically explained by Dr. A. V. Shnitnikov, seriously affected the insect and spider populations, which were drastically reduced. Later, they returned to their former level, and when the precipitation, temperature, and solar radiation combined to establish most favorable conditions, their population exploded. This was followed again by a depression of the species, even without the interference of man. Although we do not deny the tremendous effect of human activities, especially the need for drastic measure against proliferation of agricultural pests, we emphasize the value of the objective laws of nature, the knowledge of which is essential to advanced science.

Centuries ago the nomads were able to foresee the severe "koyans" and the destructive "ul'kum-dzhuts" which killed millions of domestic and wild animals. Contemporary science, however, is seemingly unable to foresee the mass outbreaks of locusts, grain moth, Eurygaster integriceps, and water voles (although the expedition of the West Siberian branch of the Academy of Sciences of the USSR has established that the proliferation of these pests in the Baraba steppe has a distinct periodicity of 10–11 years). This inadequacy can no longer be tolerated, especially since heliophysicists provide us with accurate forecasts of solar activity for decades ahead.

All possible steps should be taken to enlighten biologists and agricultural workers with respect to heliophysical data and the influence of solar radiation and its cyclic fluctuations on weather conditions and upon life on Earth.

To this end the volume of scientific and popular-scientific literature on the subject Sun–troposphere–Earth should be increased. The meteorological bulletins, reviews, and forecasts must provide, in addition to data on temperature, precipitation, and strength and direction of wind, also data on the physical state of the Sun, the presence of sunspots, their number and dimensions, and the expected general increase or decrease in solar activity, as determined by the given section of its activity curve.

A significant improvement in the long-range and extra long-range forecasts of mass outbreaks of agricultural pests might be achieved by taking into account the following three interdependent factors:

1. periodicity of solar activity;
2. regime of atmospheric circulation subordinated not only to the revolutions of the Earth around its axis, but also to the momentum of wave and corpuscular radiations of the Sun;
3. ecological changes in biocoenoses caused in time and space by the seasonal changes of the weather under the influence of the two aforementioned factors, and also by human activities.

Forecasting based on the three factors listed above does not exclude the other usual techniques of quantitative assessments of the objects under

investigation and of the biocoenotic relationship between the "hosts," and their natural enemies— the predators, parasites, pathogenic agents, etc. The importance of studying the specific reactions of individual pest species to the effects of environmental factors cannot be overestimated.

In the course of its phylogenetic evolution, each species has developed definite requirements as to environmental conditions, definite physiological optima with respect to temperature, humidity, illumination, etc. It is therefore impossible to speak in a general manner of favorable conditions for mass breeding of insects or other organisms. It is only natural that in the steppe zone the dry period will favor development and multiplication of grasshoppers while suppressing the breeding of more hydrophilous species, and vice versa. Therefore, different insects with a potentially high rate of reproduction will react differently to the rhythmic changes in the intensity of solar radiation according to the periodicity of solar activity. In this direction extensive research still remains to be done by Soviet biologists, ecologists, and plant-protection experts who have already made considerable contributions to Soviet and world science.

EFFECT OF SOLAR RADIATION ON INTRACELLULAR PROCESSES IN LIVING ORGANISMS

At the beginning of this article we mentioned Timiryazev's classical research on photosynthesis. Timiryazev maintained that chemically photosynthesis is a process by which inorganic substances— carbon dioxide and water— are converted into organic matter. From the physical thermodynamic viewpoint it is a process in which solar energy is converted into the chemical energy of organic matter. All manifestations of life on our planet and the welfare of mankind are directly dependent upon solar energy. Timiryazev, although well aware of the difficulties involved in the research of these problems, was convinced that any progress in pure or applied science required the collaboration of representatives of all branches of natural sciences, including physiologists, chemists, and physicists.

The Sun influences all beings, wrote Vavilov, and man must have a clear concept of the rule of the Sun in life on Earth so as to know what should be avoided, what can be utilized, and, as far as possible, how and what must be controlled /2/.

All the energy required for the organic syntheses in plant cells is derived from a single source— solar radiation. The synthesis of organic matter can be achieved only by solar radiation, through the agency of chlorophyll. With the aid of radiation the organism builds the molecules of protein, fat, carbohydrate, vitamins, and enzymes providing the prerequisites for chemical reactions that constitute the material basis of life /12/. The influence of solar activity is certainly not limited to photosynthesis, but covers all aspects of life on Earth.

Although we are not concerned here with the influence of solar radiation on the human organism, we should like to cite two or three instances which are directly related to all other representatives of the organic world.

About two years ago the French journal "Science et Future" published an article by A. Collo entitled "Biométéorologie." It stimulated the

interest of scientists in several institutes of the Academy of Sciences of the USSR, the Academy of Medical Sciences, and in other scientific research organizations in the USSR. The article dwelt more specifically on the reaction of colloid solutions in processes conditioned by the varying activity of solar radiation occurring in the ionosphere. "An invisible thread was stretched from sunspots to the chemist's test tube." Could that be possible? The Institute of Physical Chemistry of the Academy of Sciences of the USSR unequivocally affirmed this possibility, since some of the cosmic rays are definitely of solar origin; their intensity is directly connected with the solar flares, the appearance of sunspots, and with other manifestations of solar activity accompanied with magnetic storms on Earth.

In his article Collo mentioned that the French Academy of Medicine had established* that the incidence of severe heart disease — coronary thrombosis — is definitely connected with the advancing sunspots, i. e., intensification of solar activity. Danishevskii commented as follows: "The life processes take place in the fluid media of the organism, in solutions of electrolytes with a definite concentration of positive and negative ions. The movement of ions determines the electrical activity of tissues manifested by the biocurrents in the brain, heart and muscles; there is a known linkage of these processes in the living organism with the electrical phenomena in nature, such as polar auroras and magnetic storms, and ultimately with sunspots. The increase in the number of sunspots coincides with a higher incidence of coronary thrombosis, a fact recorded by many scientists in various countries of the world."

Investigations performed by the prominent hematologist Shul'ts have been of outstanding interest. The commission for the investigation of the Sun, at the Astronomical Council of the Academy of Sciences, had, in 1960, organized the All-Union symposium on the subject Sun–troposphere, where Shul'ts reported the results of leukopenia analyses in a hundred thousand patients. It appears that leukopenia occurred as a consequence of intensified solar activity, as verified in the course of more than the complete 11-year cycle.

If the qualitative and quantitative fluctuations in the intensity of solar radiations have such a strong influence upon the human organism, they must affect the biochemical and biophysical processes occurring in the cells of insects and other organisms, and they must also affect, directly as well as indirectly, via weather changes, the rhythm and character of proliferation of pests, which sometimes reaches the magnitude of mass invasions.

The experiments with colloid solutions reported by the Italian scientist G. Piccardi are of considerable interest. When a colloid was poured into ordinary vessels sediments occasionally settled out within a short time. In other vessels, shielded by metal covers which prevented cosmic rays and solar radiations from reaching the solution, colloids were preserved for over a year. Accurate examination of all environmental factors proved

* It should be noted that the relationship between solar activity and the state of health (functional condition of the central nervous system, proliferation of pathogens, numerous epidemics and epizootics, and total mortality) was first established by Chizhevskii's research, more than 35 years ago. His work was partially published under the editorship of Semashko, in 1926–1928. Even then Chizhevskii advanced the first valid hypothesis on the direct effect of certain solar radiation upon organic detectors. — Ed.

that the colloid solution was affected by cosmic factors, in other words, the momentum of solar activity. In the course of these studies it was established that disintegration of colloids occurred most intensively during periods of maximum solar activity, especially with the appearance of large groups of sunspots through the central solar meridian.*

We now know that it is impossible to understand the functions of an organism without exposing the molecular processes that comprise the essence of metabolism — the reactions to external environmental factors.

It is most regrettable to encounter among Soviet scientists, even among these holding leading positions in certain branches of biology, a complete lack of comprehension of the new progressive trend in science.

In a monograph on Schistocerca (1952) I stated that an understanding of the patterns of transition from isolated to gregarious forms of existence, and vice versa, requires further studies of the biochemical changes in the cytoplasm, and of the molecular structure of proteins. The latter also depends upon the intensity of ultraviolet radiation which varies according to the cycle of solar activity. The variations in solar activity during the cycle should also be studied within the complex of external environmental factors, which are still often examined with the aid of very primitive techniques, using ordinary thermometers and simple meteorological instruments, and which require improved methods in order to study the physiological effect on the locust of solar-radiation factors. This point of view encountered an ironical attitude at that time from some learned entomologists. Even the press used to insert exclamations such as "Let the reader himself judge the relationship this bears on locusts."

It is certainly simpler and easier to count or measure appendages of dried locusts in museum specimens than to break new ground in the complex field of the biophysical and biochemical patterns of the living organism, to trace down to their roots new facts in processes of the intracellular microscopic world, which also determine the morphological changes of organisms.

It is hoped that at this stage the reader will be able both to assess correctly and to condemn in clear terms those scientists who persist in their obsolete positions and have no understanding of the new and most promising trend in scientific research.

There is no doubt that times have changed and that our scientists will be equipped with the most progressive methods and apparatus for their laboratories, which will help in understanding the complex processes of intracellular biochemical and biophysical reactions determining the metabolism and the biological patterns in the lives of individual species, especially of those causing mass reproduction.

It is with special satisfaction that we mention the research carried out by the German scientist Müller /14/. He analyzed the contents of purine and pyrimidine bases in deoxyribonucleic acid extracted from migratory locusts, and obtained remarkable results. Müller noticed that maximum absorption of ultraviolet rays by deoxyribonucleic acid is precisely at that wavelength that has the maximum biological and mutagenic effects, namely at wavelength 260 mμ.

* For details of G. Piccardi's work the reader is referred to the paper "Physicochemical Reactions as Indicators of Cosmic Phenomena" by A. L. Chizhevskii, in this collection.— Ed.

Several other scientists outside the USSR, in Europe and America (Carlson, McAlister, Tahmisian, Schneider, Hollaender, Latarjet, Holden, and others), are engaged in studies of the effect of ultraviolet and radioactive radiations on the state of the neuroblasts of certain species of orthopterous insects, on the phenomenon of embryonal diapause, and on many biochemical and biophysical processes in their bodies.

We maintain that this trend in the study of patterns, especially of mass reproduction in locusts, is most promising and desirable because of its great theoretical value and practical importance in the protection of crops.

In view of the achievements in the allied sciences, especially biochemistry and biophysics, and the availability of suitable equipment for microanalyses, entomologists are expected to move forward and to pass from the "classical" methods of breeding insects in incubators to the use of labeled atoms and electron microscopy. This will permit a deeper analysis of the processes occurring in the cells of the insect, and uncover the molecular relationships and explain the effect on them of the entire complex of external environmental factors, including the variable solar radiation and the corpuscular invasion of the Earth's atmosphere.

In modern scientific terminology, "molecular biology" has justifiably become a common term.

In his speech at the Moscow international symposium in 1957 on the problem "Origin of Life on Earth", Academician E. N. Pavlovskii stated that physiological functions originated in the process of formation of living matter revealing its cardinal function: metabolism. This in turn was related to morphological differentiation of primary organisms and their subsequent evolution. In the process of scientific specialization morphology and comparative anatomy evolved naturally toward functional morphology and biochemistry of developing organisms /15/.

It is our opinion that precisely this approach to the still unknown processes and phenomena is the most likely to lead toward understanding the existing patterns, while elaboration of the theoretical principles involved in the development of organisms will open the way toward useful implementation of the scientific achievements in socialist agricultural practice.

REFERENCES

1. EIGENSON, M. S. Ocherki fiziko-geograficheskikh proyavlenii solnechnoi aktivnosti (Physicogeographic Manifestations of Solar Activity), Lvov. 1957.
2. VAVILOV, S. I. Glaz i Solntse (The Eye and the Sun). — Izdatel'stvo AN SSSR. 1956.
3. BERG, L. S. Solnechnaya aktivnost' v geologicheskom proshlom (Solar Activity in the Geological Past). — Priroda, No. 4. 1947.
4. SHOSTAKOVICH, V. B. Ilovye otlozheniya ozer i periodicheskie kolebaniya v yavleniyakh prirody (Lacustrine Silt Deposits and Periodic Fluctuations in Natural Phenomena). — Zapiski Gosudarstvennogo Gidrologicheskogo Instituta, Vol. 13. 1954.

5. SHOSTAKOVICH, V. B. Sloistye ilovye otlozheniya i nekotorye voprosy geologii (Stratified Silt Deposits and Certain Geological Problems). —Izvestiya VGO, No. 3. 1941.
6. SHVEDOV, F. M. Derevo kak letopis' zasukh (The Trees as Drought Chroniclers). — Meteorologicheskii Vestnik. 1892.
7. SHCHERBINOVSKII, N. S. Pustynnaya sarancha shistotserka (The Desert Locust Schistocerca). — Sel'khozgiz. 1952.
8. MITCHENER, A. — Bulletin of Winnipeg University, Canada, No. 8. 1956.
9. BROUNOV, P. I. (after B. P. Alisov). Kurs klimatologii (A Course in Climatology). 1952.
10. MARIKOVSKII, P. I. Yadovityi pauk karakurt (The Poisonous Spider Karakurt). — Zoologicheskii Zhurnal, Vol. 22, No. 3. 1953.
11. SHAKHMATOV, V. O proiskhozhdenii 12-letnego zhivotnogo tsikla letoschisleniya kochevnikov (Origin of the Nomads' Animal Calendar of the Twelve-Year Cycle). — Vestnik AN Kazakhskoi SSR, No. 1. 1955.
12. RABINOVICH, E. M. Fotosintez (Photosynthesis). 1951.
13. PAVLOV, I. P. Lektsii po fiziologii (Lectures in Physiology), p. 66. — Izdatel'stvo AN SSSR. 1949.
14. MÜLLER, W. Biochemistry of Hereditary Factors. [Russian translation. 1957.]
15. PAVLOVSKII, E. N. Vozniknovenie belkov, fermentov, nukleproteidov. (Origin of Proteins, Enzymes, and Nucleoproteins), A Discussion . — Trudy Mezhdunarodnogo simpoziuma 19–24 avgusta 1957 g., pp. 363–365. Moskva, Izdatel'stvo AN SSSR. 1959.

PART FIVE
BIOSPHERE OF THE EARTH AND PHYSICAL FIELDS

M.S. Eigenson

ABUNDANCE OF ORGANIC MATTER IN THE UNIVERSE

Life is a natural phase in the development of matter— the highest form of its evolution inevitably arising when the necessary prerequisites are present. Insofar we know, cosmic inorganic matter is chemically homogeneous throughout the investigated part of the infinite universe. It is organized into celestial bodies and their systems in a definite recurring order. As the organic and the inorganic substances represent two forms of matter which are essentially the same, it may be said that the living organisms throughout the universe are possibly composed of the same chemical elements as the terrestrial living organisms, i.e., of protein substances and are everywhere morphologically similar to those on Earth.

Since the universe is infinite and external, it follows inevitably from the above that some traces of organic life should exist everywhere in the universe. Possibly, these traces of life in the universe should be the rule rather than the exception owing to the "ubiquity of life," to quote the inspired expression of V. I. Vernadskii. Philosophically, the task of searching for traces of the organic phase in the development of cosmic matter is therefore justified wherever and whenever possible.

It is quite evident that adequate development of direct (rocket) exploration of our cosmic environs is prerequisite to any direct contact with extraterrestrial organic life, and primarily with Mars, where the presence of life has been suspected for a long time. Meanwhile, we can only base our discussions on observations from the Earth recorded by the classical techniques of optical astronomy. Spectrum analysis is the most efficient method of optical astrophysics. However, for the detection in the universe of some complex molecule, and particularly a protein molecule, the possibilities of spectrum analysis are naturally limited. Thus, if we refer to the radiation spectrum, any complex molecule will be dissociated before any thermal radiation will be apparent. In "cold" high-frequency fields it was possible to excite radiation spectra of complex organic molecules. In order to produce a measurable absorption spectrum, the optical density of the corresponding substance must be fairly large. It is evident from the above that spectroscopic detection of complex polyatomic molecules that might be in the universe— even in great numbers— is impossible at present.

In addition to inorganic molecules and relatively simple carbonic molecules, the decomposition products of highly organized proteins simultaneously provide the initial chemical raw material for further natural organic synthesis.

In general, the simplest organic molecules are thermally considerably more stable than the more complex organic molecules. Therefore, their spectroscopic detection may be relatively easier.

At present, astrospectroscopy actually reveals organic matter in the universe consisting of the simplest carbonic molecules, but fails to detect more complex organic compounds. These findings may be interpreted as an indirect indication of the possible existence of complex organic compounds but cannot be taken as proof of their nonexistence.

Let us consider an analogy with the detection of microscopic inorganic cosmic dust by absorption. Although absorption of the larger solid particles and small bodies is not detected, the astrophysicists have no doubt of their existence (and even abundance) in interplanetary space. Thus, it seems that in both cases we are able to detect only one, well-defined part of the spectrum.

Astronomical observations have demonstrated that the universe is abundant in the simplest organic compounds. This abundance, and possibly even profusion, is of utmost importance for the natural sciences, and of profound philosophical significance. It is regrettable that the relevant astrochemical findings have, until recently, been put aside, essentially without having been generalized. The presence in the universe of organic substances is of utmost scientific importance.

For the time being this fact is mainly of a qualitative character. Some more time, and possibly a long time, will be required before any accurate, quantitative analysis of the cosmic organic compounds can be made.

The presence of primary molecules of organic compounds in the solar system has been established beyond doubt by spectrum analysis. These molecules are found particularly in comets and meteorites, in the atmospheres of large planets and some of their satellites, as well as in the atmospheres of cold stars and in interstellar space.

The presence in the universe of the simplest molecules that may combine to form organic matter might indirectly prove the presence there of more complex organic compounds as well (and possibly also of organisms). Another indirect argument supporting this hypothesis is the release of certain gaseous products in the course of gradual changes of the organic matter buried in terrestrial sedimentary rocks. It may be more than mere coincidence that these gaseous products are of precisely the same composition as the cosmic— organic and inorganic— gas.

Enormous quantities of natural methane exist in the atmospheres of the Jovian planets and this is also true for the Earth. The Earth's "gaseous respiration" (mainly methane) during the $4.5–5 \cdot 10^9$ years of "geological time" (which is the "age" of terrestrial matter) must have amounted to at least 10^{-5} of the entire present-day mass of our planet. Insofar as can be assessed from the available, still quite fragmentary data, the total amount of even the simplest organic compounds in the universe is probably quite large, in absolute and possibly even in relative terms. This is just what one would expect assuming that (a) the organic matter in the universe is biogenic, and (b) organic life, being "ubiquitous," has propagated throughout the infinite universe during its eternal existence.

In concluding this preliminary note, we refer to some of the ideas presented in the preceding paragraph. From the point of view of dialectic materialism it is quite natural to expect not only abundance, but even profusion of organic matter in the universe, on the basis of its biogenic

character. Any attempt at this stage to determine whether the observed cosmic organic compounds are the remains of organisms, or the initial organic raw material for their synthesis in nature, or both, is obviously premature. It is doubtful whether in nature life inevitably arises in each given suitable cosmic body, always from the "zero point of organic life," i. e., always and everywhere along the long and complex biochemical path of synthesis of the simplest organic molecules from the inorganic ones.

To the best of our knowledge the initial organic raw material is disseminated everywhere in the universe. The universe is the natural material basis for resumption of life wherever it might have been discontinued for a time, following certain cosmogenic events which had affected only the character of macroscopic organization of matter in celestial bodies and their planetary systems, but had left unchanged the chemism of that matter and, especially, the molecular structure of the simplest organic molecules.

A.L. Chizhevskii

ATMOSPHERIC ELECTRICITY AND LIFE

Almost a century ago (1887) Charles Darwin considered electricity as one of the possible factors in the origin of life on Earth. A more distinct correlation between the formation of organic compounds and electrical phenomena in the atmosphere was formulated in the 1920's. In 1939, R. Beutner indicated the powerful electric discharges in the atmosphere as a factor facilitating the synthesis of certain amino acids. During the years 1938–1947, the French scientist A. Dovillier repeatedly stated that these discharges must have contributed to the synthesis of high-molecular organic compounds. Such formations, by means of diverse spatial combinations of the particles throughout countless millenia, might have accidentally led to the emergence of the simplest organisms. Nature required many billions of various chance combinations before it produced the primary, self-reproducing life substance, resembling the filterable virus, followed after considerable time by the appearance of the first microorganisms: the bacilli. Dovillier maintained that the probability of metabolism and self-reproduction in such chance combinations of organic molecules is very small.

All these speculations concerning the role of electrical discharges in the atmosphere would have remained mere hypotheses or theoretical assumptions, had it not been for remarkable syntheses performed a few years ago (1953) by the American scientist S. Miller in his laboratory on the basis of modern concepts concerning the composition of the primary terrestrial atmosphere. By means of a high-voltage installation he produced silent electrical discharges in a mixture of methane, ammonia, hydrogen and vapor, and obtained a series of amino acids: glycine, alanine, sarcosine, and aminobutyric acid. He also obtained glycolic, lactic, formic, acetic, propionic, and other acids.

Miller reported that as a result of the electrical discharge, cyanic acid, amines, aldehydes, alcohols, large amounts of volatile acids, and acrylonitriles were formed. All these substances were formed in the gaseous phase by the silent electrical discharge as a result of reactions of free radicals and ions. Consequently, at some time electrical discharges were instrumental in converting nonliving matter into living matter...

It should be mentioned that these ideas were expressed by the author of this article sixteen years before Miller (in 1937), and published under the editorship of A. Errer.

THE TEACHINGS OF HIPPOCRATES

It should not be thought, however, that the effect of atmospheric electricity remained confined to the formation of the first structures of organic compounds. Living organisms continually absorb ions— "electrical corpuscles"— from the air ocean, using them to maintain the most important life processes. The famous Greek physician Hippocrates noticed 2300 years ago, the difference between outdoor and indoor air, and that the latter is distinctly beneficial for human health. In addition to prescribing medicines, he ordered his patients to take long walks by the sea shore or in the mountains. This advice recurs in the Hippocratic Collection (such as the treatises on "The Sacred Disease," "Epidemics," "Airs, Waters, Places." Physicians in ancient times believed that "Air is the pasture of life," and built "aerariums"— platforms where the patients could expose their bodies to the open air. Aerotherapy has been adopted by modern physiotherapy. Eastern wisdom shared the classical Greek belief in fresh air, as reflected by the proverb "It is better to take another walk than keep a medicine chest at home."

The importance of air was vividly described by the Soviet writer P. A. Pavlenko in his novel "Happiness." The physician Komkov says to his patient: "Your illness requires a simple medicine— air. More air while you are awake or asleep. You must let yourself be aired throughout, every cell in your body must be washed with fresh air... You should eat in the open and sleep in the open... So, begin to take air in unlimited doses. Learn to breathe. Get used to regarding air as food, masticate it with your nasopharynx, taste its flavor, enjoy it as a gourmet... Drink only flowing air... In your illness, adopt the open-window practice..."

In his novel "A Floating City" (1895), Jules Verne plans "a visit of the floating city to the principal archipelagos of the eastern Pacific, where the air is remarkably salubrious, very rich,.. in oxygen— condensed oxygen, saturated with electricity, and possessing revitalizing properties that are usually absent from oxygen in its ordinary state."

Studies of the biological effects of atmospheric electricity started early in the twentieth century. The famous Swedish physicochemist Svante Arrhenius demonstrated the effect of fluctuations in atmospheric electricity upon certain human physiological functions. At the end of the last century, the Russian hygienist Irinarkh Skvortsov also stressed the importance of atmospheric electricity in the life activities of an organism.

AIR IONS AND CHARGED PARTICLES

Although studies of atmospheric electricity started in the middle of the eighteenth century, it was only at the very end of the nineteenth century that the carriers of this electricity were found to be molecules of the air gases, which are converted from neutral particles to negative or positive ions by acquiring or losing elementary electric charges. The nature of such ions is clearly described by Academician N. N. Semenov in his book "Electron Phenomena" (1928).

"The role of the atom's outer electrons is most convincingly demonstrated by the properties of ions. For example, when the single peripheral electron is detached from a sodium atom, its position is assumed by the inner group which is peripheral in neutral neon. Apparently, this sodium ion has properties which differ entirely from those of the sodium atom, but which resemble those of neutral neon (the preceding element in Mendeleev's Periodic Table— A. Ch.). We know, for example, that the sodium ion remains chemically inactive, similar to neon. The spectrum emitted by a sodium ion has nothing in common with that of sodium, but closely resembles the nion spectrum. The atomic volume of a sodium ion is only a fraction of that of the sodium atom. The same can be said about the magnetic properties of ions. In all cases, ions of a given atom resemble its preceding element (in the Periodic Table— A. Ch.), and in case of double ionization, the element before the preceding one."

The phenomenon of surface charging differs fundamentally from ionization. Charging consists in separating the positive and negative charges on the body surface. An excess of positive charges may appear on certain bodies, and of negative ones on others. The total of positive and negative charges equals zero. Charging always occurs when one body rubs against another, when water is atomized in air, when solids are pulverized, and in the course of other physical and chemical phenomena. Almost everything in the world is electrically charged. Dust, smoke, spray, and air pollutants are all charged, although they are quite inactive biologically. It is time for scientists to recognize this physical fact and thoroughly study its ramifications.

Hence, there is a fundamental difference between the ionization of molecules and atoms, and the surface electricity of bodies. Air contains light gas ions, or air ions and their aggregates, and at the same time solid and liquid dust particles of microscopic dimensions with charged surfaces devoid of any signs of true ionization.

IONIZATION OF ATMOSPHERIC OXYGEN

More than 40 years ago we reported the negative charge acquired by a atoms or molecules of atmospheric oxygen. The experimental proof of this fact was published in 1933. Many years later the same phenomenon was studied by Marcel Laporte and other scientists, and today, it is completely accepted.

Rutherford's famous experiment of 1919 is very well-known. He demonstrated that bombarding the nucleus of the nitrogen atom with alpha particles changes the number of protons per unit in the nucleus, transforming the nitrogen atom into an oxygen atom— an element found next to nitrogen in Mendeleev's Periodic Table. This was the first experiment in the "transmutation of elements."

When a metal needle is subjected to a strong negative charge, electrons being to escape rapidly from its sharp point, i.e., an avalanche of electrons of high kinetic energy is caused. This process is enhanced by molecules of atmospheric oxygen owing to the property of oxygen atoms to "extract" electrons from metals. This phenomenon is known as electron

or electrostatic emission. We used sharp needles because the quantity of electricity is directly proportional to the square root of the surface curvature.

The electron avalanche is similar to a chemical chain reaction, or to the proliferation of microbes on a suitable nutrient medium. It produces a multitude of negative ions of atmospheric oxygen spreading very rapidly in all directions from the fine point ("ionization current" from the point).

As we have already seen, a single ionization of an atom renders it similar to the neighboring element in the Mendeleev Table, with respect to many parameters, and after double ionization it resembles the one after the next element. Since ionization affects mainly the electron shells it is unrelated to the complete "transformation of elements."

Nevertheless, after negative ionization the oxygen atom develops a certain resemblance to the neighboring element, and after double ionization, the one after the next element in Mendeleev's Table. The oxygen atom has eight electrons in accordance with its atomic number (Mendeleev number). The negatively ionized oxygen atom gains one or two electrons. This means that after a single ionization some of its most important physical properties begin to resemble those of the fluorine atom (nine electrons), while after double ionization it resembles that of neon (ten electrons). Consequently, we decided to study phenomena of special biological significance.

Apart from the physical aspect (ionization) this also constitutes a physicochemical problem, since the principal physical parameters of an oxygen atom with ten electrons require further study. In addition to the electrical process related to the electron structure of the atom shells, physicochemical processes also affect biological reactions. These circumstances obviously complicate the study of mechanisms of the biological effect of air ions.

Positive oxygen ions have no effect, and may even prove injurious, when the oxygen ion is left with only seven electrons (corresponding to nitrogen) or with six electrons (corresponding to carbon). It is well known that carbon does not occur in the gaseous state. Nevertheless, an oxygen atom deprived of two of its electrons must resemble carbon in some of its properties. An oxygen atom with a double positive charge might combine with an atom of ordinary oxygen to form something resembling poisonous "carbon monoxide." Indeed, inhalation of positive air ions causes dyspnea, giddiness, marked lassitude, etc. This is another aspect of the problem requiring further study.

The statements made above may be tabulated as follows:

Atomic number Number of electrons in the atom	6	7	8	9	10
Charge	++	+	neutral	—	——
Chemical symbol of the element	C	← N	→ O ←	F →	Ne
Name of the element	carbon	nitrogen	oxygen	fluorine	neon
Physicochemical changes of the oxygen atom following positive (++ and +) and negative (– and – –) ionization	Positive oxygen ions resemble nitrogen and carbon			Negative oxygen ions resemble fluorine and neon	

These facts compel us to study the ionization of gases as a biological factor, disregarding the notion that charging is biologically inactive.

Furthermore, our attention should be focused on the biological effect of the electronic shell of oxygen carrying a single negative charge— the "fluorine." We use quotation marks because the oxygen of single negative charge occupies, as it were, an intermediate position between oxygen and fluorine; hence, its effects on the organism should be analyzed separately, especially in connection with the fairly extensive use of fluorine compounds in the chemotherapy of malignant tumors (A. Chizhevskii, L. Vasil'ev, E. Küster, F. Dittmar, B. Sokolov, W. Eddy, L. Strel'tsov, R. Blay, I. Williams, L. Ziortini, L. Larionov, and others).

CHANGES INDUCED BY IONIZATION IN THE NUCLEUS OF THE OXYGEN ATOM

Until recently it was assumed that ionization changed only the electron shells of atoms or molecules. This opinion was firmly established theoretically as well as experimentally by various accurate physical analyses of ionized gases.

In order to explain the hyperfine structure of atomic spectra Pauli advanced, for the first time, the hypothesis that in addition to their electric charge the atom nuclei also possess magnetic moments. If a system of nuclei having magnetic moments is placed in a magnetic field, the moments will be acted upon by couples of forces, aligning them in parallel with the field. With appropriate techniques, the magnetic moments were caused to absorb the energy of a variable magnetic field oscillating at radio frequencies. Such absorption gives rise to the nuclear magnetic-resonance spectrum. The latter is absent in the case of nuclei devoid of magnetic moments.

Recent studies on high-resolution nuclear magnetic resonance spectra firmly established that any changes induced in the electron shell of an atom are reflected in the physical properties of the nucleus of the ionized atom. This was a tremendous achievement of modern science since it proved the direct relationship between the physical (electron) parameters of the atom shells and the physical parameters of the atomic nucleus (protons). For instance, the nuclear spin (angular momentum) tends to orient the spin of the electrons surrounding the given nucleus, and these in turn orient the spin of other electrons; the interaction is usually expressed in cycles per second, using the Planck constant as the unit of energy. The observed energies range from 1000 cps to very small values, at the limit of sensitivity of the recording instruments (J. Pople and others).

It has been established that nuclear spins are coupled through the orbital motion of electrons, and this fact is especially important for the theory of the biological effect of air ions. Hence, the constant of spin-spin interaction is determined by the coupling between the orbital motion of the electrons with the magnetic moments of the nuclei. This interaction is readily explained by the simple classical concept that the magnetic moment of each nucleus induces a certain current in the molecule which, in turn, generates a magnetic field that acts upon another nucleus (MacConnell).

In their analyses of the nuclear magnetic resonance spectra, physicists could use the nucleus as a test magnet in studies of local magnetic effects of intramolecular systems. The local magnetic field in the vicinity of a given nucleus depends upon the chemical nature of the nucleus, and is determined by several factors including polarization of certain sectors of the specimen, magnetic moments (nuclear and electron) of the neighboring molecules, and the intramolecular effects related to other nuclei and electrons of the same molecule in the liquid and gaseous states (H. Bernstein and others). Improved experimental techniques made possible high resolution of the indivudual nuclear resonance signals and greatly accelerated the application of this method to a wide range of physicochemical problems. This is particularly relevant to the oxygen molecules. The molar paramagnetic susceptibility of the oxygen molecule, at 20°K, is considerable. The paramagnetic susceptibilities are approximately 100 times higher than the diamagnetic ones. Atmospheric oxygen dissolved in the specimen may distort the nuclear magnetic-resonance spectra of the specimen being analyzed. The presence of paramagnetic ions gives rise to local magnetic fields, that change the lifetimes of the nuclear-spin states and consequently the width of signals (J. Pople).

Signal displacement was recorded in salt solutions containing paramagnetic ions (Bloembergen, Dickinson). These shifts are best explained by the direct interaction of unpaired electrons with the protons that determine the hyperfine structure of the electron paramagnetic resonance spectra.

The interaction of atmospheric oxygen ions with living organisms is thus highly complex. Studies of it therefore require thorough knowledge of the recent developments and achievements of physics, physical chemistry, and biophysics. Many clinicians studying the curative effect of air ions have apparently been lacking in this knowledge, and have consequently reached erroneous conclusions.

OUTDOOR AND INDOOR AIR

In frosty weather the air we exhale is visible, as a white cloud of vapor. In warm weather, the exhaled air, though invisible, contains numerous liquid particles and diverse organic and inorganic products of gas exchange. A single exhalation whose volume is approximately 500 cm^3 contains 200 million particles, 75% of which are charged. During eight hours of sleep, one person exhales about two trillion particles into the bedroom air. The mass of exhaled particles rapidly disperses, and by diffusion, gradually fills the entire room, literally polluting its air. Some of the exhaled particles combine chemically with the oxygen in the air, thereby "spoiling" it. As a result of their minute size, these particles settle very slowly, and take part in thermal motion.

Measurements and calculations have shown that one person can rapidly pollute the air, even in a large room, with his respiratory wastes, and consequently he soon begins to inhale his own wastes. If water is mechanically sprayed in an inhabited room (with an atomizer), the respiratory-waste particles settle on the droplets, converting the charged particles of the sprayed water into charged aerosols which are detrimental

to health. This phenomenon, experimentally confirmed (1933–1934), requires a very cautious attitude toward the so-called "hydroionizers," which atomize charged water mists without ionizing the oxygen of the air.

Different processes occur when water is mechanically dispersed outdoors, such as in the sea by the surf, or during heavy rains, at high waterfalls, and near rapid mountain streams. In the natural environment, the air oxygen may condense on the surface of charged water particles, and with sufficient kinetic energy the oxygen molecules acquire a negative charge, thereby becoming true air-ion aggregates, or "heavy" air ions.

In addition to its intrinsic salubrious properties (due to its ionic content), fresh outdoor air is also healthy because a man breathing such air does not inhale his own respiratory wastes, as he must do indoors. This fact is of great importance, and must be considered when examining the conditions of the "indoor" air breathed by people in enclosed premises. The builders of our houses must bear this in mind, and should therefore provide for air ionization throughout the building; this target can be achieved within this decade.

NUMBER AND CHARGE OF AIR IONS OUTDOORS AND INDOORS

Outdoor air contains both positive and negative ions, with the former generally being somewhat more numerous than the latter. This situation is of no danger to healthy people, because the small predominance (by 10–20%) of the positive air ions is offset by the considerably higher mobility, diffusion, and ionization of the negative air ions. However, in certain localities the negative air ions permanently outnumber the positive ions. Because of this property of the air in some resorts (Sestroretsk, Alma-Arasan, Abkhazia, etc.) we call them "electrical resorts." The average number of light air ions (both positive and negative) over the greater part of the globe, is approximately 1000 per cm^3, fluctuating according to the season, time of day, and geophysical, meteorological, and other conditions.

Ionization of atmospheric air occurs mainly as a result of decay of the radioactive elements, always present in minute quantities in soil and water. Cosmic radiation excites from one to 2.8 pairs of ions per cm^3/sec. Solar flares usually lead to the abrupt rise in the intensity of cosmic radiation accompanied with a slight, temporary increase in atmospheric ionization.

Research has revealed that the concentration of air ions in summer is considerably higher near green plantations and over meadows than in other places. The difference is most pronounced in cities in the vicinity of factories where the concentration of light air ions drops abruptly, while the increase of charged liquid and solid aerosols is recorded; the latter are generally very damaging to health.

The higher concentration of air ions in the vicinity of green expanses is readily explained by the extensive surfaces giving off radioactive water from the soil through the foliage or herbage. The leaf area of forests and meadows exceeds tens of times the soil area covered by the plants; in the grass meadows which we investigated (temperate latitudes) it is, on the average, 25 times greater, and in the alfalfa fields 85.5 times. This is

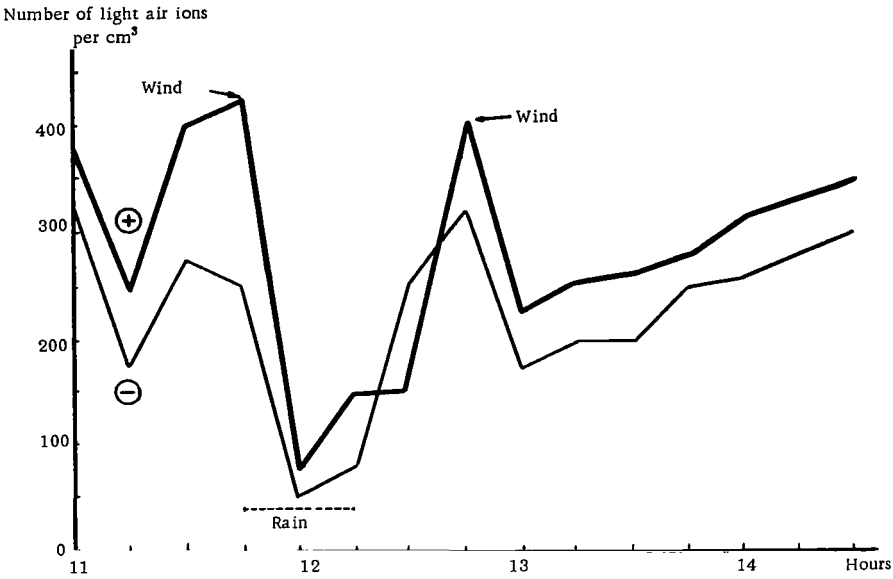


FIGURE 1. Dynamics of the light air ions of positive and negative charges measured at the level of human height. In wind and moderate rain.

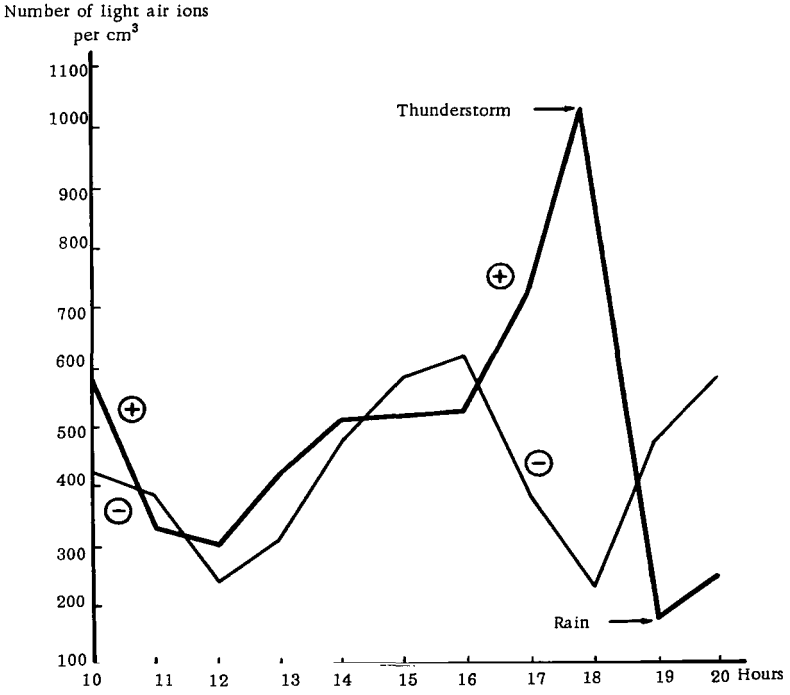


FIGURE 2. Dynamics of the light air ions of positive and negative charges measured by the author at the level of human height during a thunderstorm with rain.

the rational explanation for the salubrious effect of green expanses in the cities.

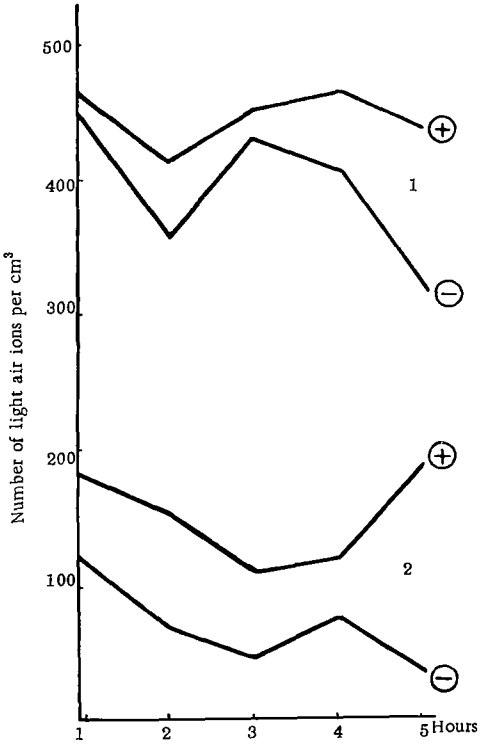


FIGURE 3. Dynamics of light air ions: above—outdours on a sunny summer day; below—simultaneous measurements in a room, at the ventilation aperture (electric fan).

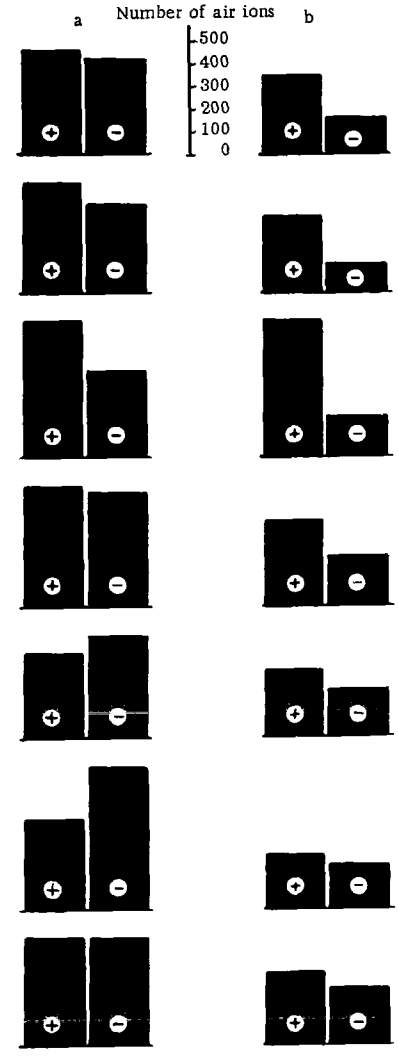


FIGURE 4. Average number of air ions of positive and negative charges measured simultaneously outdoors (a), and in a room with closed windows (b).

Our investigations revealed that when air enters closed premises through windows, cracks, and ventilators, it loses almost half its light ions. In the presence of people, the number of light air ions indoors rapidly falls toward zero, owing to the large number of neutral and charged particles

exhaled by the human respiratory system. Consequently people spend most of their life in deionized air. In air-conditioned rooms the air is devoid of any light ions. Let us now examine whether the absence from the air of light oxygen ions influences human health and life.

INJURIOUS EFFECTS OF AIR DEVOID OF AIR IONS

In the last decade of the past century, the Russian hygienist I. I. Kiyanitsyn advanced the concept of "oxidizing microorganisms," which were supposedly always spinning in the air together with which they reached the lungs and penetrated into the blood, facilitating the process of oxidation in tissues and organs. The idea seemed most improbable, even at the time it was advanced, but Kiyanitsyn was convinced of its validity and strove to substantiate it experimentally. His experiments, performed at the laboratory of Academician V. V. Pashutin, proved to be very simple. Experimental animals were placed in a hermetically sealed glass chamber into which air was pumped through a glass tube loosely packed with hygroscopic cotton. Kiyanitsyn assumed that all "oxidizing microorganisms" would be retained in the cotton plug, and the experimental animals (rats, guinea pigs, rabbits, dogs, and pigeons) deprived of these microorganisms would die, notwithstanding the ample supply of food and water, and the generous exchange of air.

Indeed, Kiyanitsyn's experimental animals and birds invariably did perish, and the respective analyses proved that their death was caused by the reduced rate of oxidation in their organisms, i. e., accumulation of products of incomplete oxidation in urine, the abrupt fall in their body temperature soon after experiments began, etc.

At that time scientists did not pay proper attention to these studies. In 1915, the present author studied Kiyanitsyn's work and found it extremely interesting and faultless, except for his interpretation of the results be obtained. By that time, atmospheric electricity and air ionization had already been adequately substantiated by physicists. In 1918, this author undertook a series of experiments which clearly revealed that negative air ions had a beneficial effect on animals while positive air ions were generally detrimental. It was also established that the cotton filters used by Kiyanitsyn absorbed all air ions as well as all charged particles from the air.

IMPORTANCE FOR HUMANITY

The effect of air filtered through cotton was studied by us and by our supporters who continued the experiments in considerable detail. Notwithstanding the excellent air exchange in the chamber, the filtered, totally deionized air proved injurious. Sooner or later all experimental animals perished, showing signs of sudden suppression of the oxidative processes, as established by thorough analyses of their tissues and organs. It was proved that filtered air had the same effect on the organism as lack of

oxygen, i.e., oxygen starvation. Most remarkably, this "oxygen starvation" was recorded in conditions of normal oxygen concentration in the inhaled air, and at the usual partial pressure.

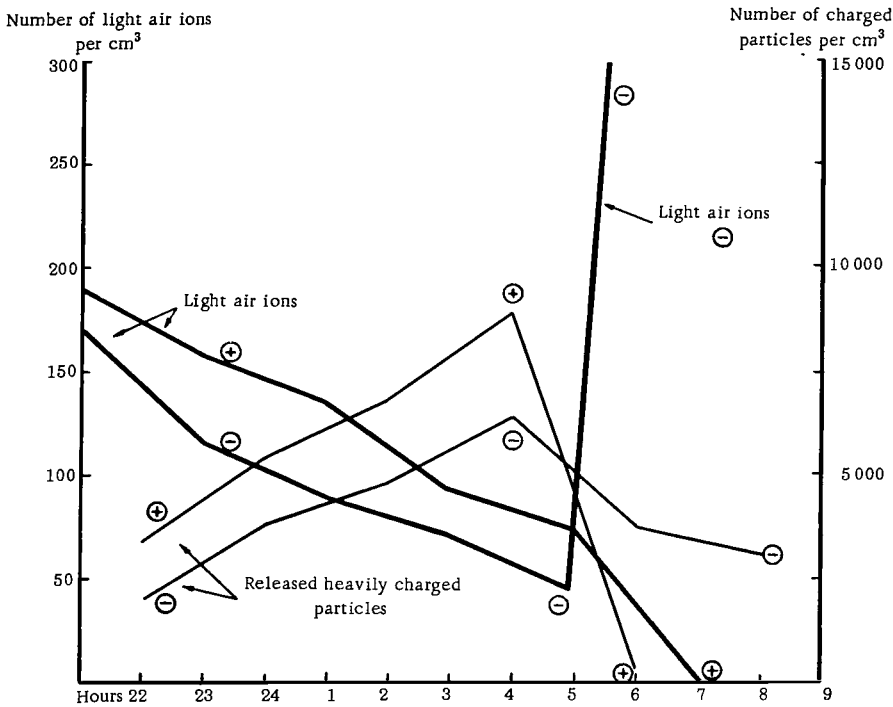


FIGURE 5. Air ionization of an inhabited room. Dynamics of air ions and charged particles. Artificial ionization started at 4 hr 55 min (negative charge). Measurements by the author.

Kiyanitsyn's hypothesis of "oxidizing microorganisms" has long since been discarded. It had to be recognized that the experimental animals ultimately died for want of oxygen ions, which were absorbed by the cotton filter and converted into electrically neutral oxygen molecules. This transformation was also proved experimentally.

In a second series of experiments, the filtered, and hence deionized air was artificially ionized; the animals inhaling this air showed no signs of illness and did not die. The close relationship between oxygen and negative electricity was thus established experimentally for the first time. Our experiments were conducted at the Third Medical Institute (in the department headed by Prof. V. K. Varishchev) between 1937 and 1942. We obtained results of outstanding importance for the entire human population which spends 0.9 of its life indoors.

Every inhabited room should be regarded as a chamber with filtered air lacking the required amount of negative oxygen ions. The significance of this fact imposes on us tremendous responsibility toward the present-day human population and its descendants. It compels us to improve the air within inhabited premises; air purified by ventilation should be artificially

ionized with negative charges to concentrations equal to those found in pure country air, on a fine summer day. This measure was designated by the author as air ionization of inhabited premises (1931). All attempts at disproving the biological fact established by us have failed.

THE OUTSTANDING IMPORTANCE FOR LIFE OF NEGATIVE AIR IONS

In simultaneous studies of the fundamental significance of oxygen ions in the air the author, coworkers, and supporters — biologists, physiologists, and physicians — conducted numerous experiments on animals, and recorded their observations of human patients in connection with the action of light air ions of positive and negative charges. These experiments and observations confirmed the salubrious effect of negative ions, as first established by the author, and the indifferent, or occasionally unfavorable effect of positively charged ions. The Central Research Laboratory of Ionization (TsNILI) was organized in Moscow in 1931 for the practical application of negative air ions, and a special laboratory was later organized by the Construction Authority for the Palace of the Soviets.

The mechanism of physiological action of air ions — of either charge — has been carefully and thoroughly studied since 1918 in a joint effort by the author and his colleagues. Special observations have demonstrated that negative ions are most beneficial for growing organisms, weakly developing organisms, and weakened, fatigued, and old organisms.

Medical investigations corroborate the regenerating, strengthening, invigorating, preventive, and curative effect of negative ions. Numerous illnesses can be successfully treated with negative ions in 85% of the cases. Special investigations proved that there are no counter indications to the use of natural concentrations of negative air ions in either sick or healthy people. This finding was substantiated by hundreds of medical investigations carried out by physicians over a period of about forty years. This is quite understandable considering that atmospheric ions are a natural and necessary factor for life. We shall not dwell here in detail on the medical application of air ions; this was recommended by the People's Health Commissariat of the USSR, as early as 1930–1931, for extensive use by preventive and curative medical institutions. The biological effect of air ions has been thoroughly reported in numerous works published by the author and others (the bibliography of this subject includes about 2500 works in different languages), and has been reviewed in the monograph "Air Ionization in the National Economy" (Gosplanizdat, 1960). In collaboration with physicians, the author investigated the effect of negative air ions on miners working underground, in the Karaganda coal basin. The number of sick days caused by common colds and other diseases (according to the sick lists) in the experimental groups amounted to only half that number in the control groups. The salubrious effect of the negative atmospheric oxygen ions is explained by modern bioenergetics, studies on the biological consequences of the electron levels of organic molecules, and the principles of quantum mechanics.

The above-mentioned monograph quoted K. E. Tsiolkovskii, who, in the 1920's, after reading the author's work on the artificial ionization of air predicted the use of air ions in spaceships.

The beneficial effect is conferred only by the light oxygen ions produced by a silent discharge of negative electricity into the air.

In the decision No. 12-8/2188, of 29 April 1962, the State Sanitary Inspection of the USSR approved the use in polyclinics and several kinds of workshops of effluvial point-discharge ionizers producing up to 5000 ions per cm^3.

AIR IONIZATION IN FACTORIES

This field is of direct concern to the institutes of labor protection, hygiene, and occupational diseases. Air ionization is of special importance in workshops and factories with high concentration of dust particles of various origins that might endanger health or carry a positive electrical charge. Air ionization facilitates control of air pollution in factories and workshops because the negative ions are always discharged at the top of the building (irrespective of its size and volume) while the ground is always under a positive potential. Without this, complete purification, or sterilization of air is impossible. The mechanism of this phenomenon is very simple. The airborne dust particles or microorganisms are charged by the negative ions to a certain potential, and move in the electric field toward the positive pole along the field's lines of force. The experiments we conducted during 1933-1942 demonstrated beyond doubt this remarkable property of negative air ions, obtained with the effluvial ionization method. Engineer N. D. Kiselev in 1954-1957, physician T. S. Timurziev in 1956-1957, microbiologist-physician E. Yu. Zuikova, and Engineer A. I. Frank in 1958-1961 fully confirmed the possibility of successfully controlling dust and microorganisms in public buildings, workshops, and factories.

Moreover, it was proved experimentally by Kiselev that the same method could be applied to the removal of dust and other aerosols from the vast amount of gases discharged into the atmosphere through the chimneys of various factories. Purification of polluted air in industrial cities, one of the most important problems in hygiene, might be successfully solved by installing air-ionizing units in factory chimneys.*

The manufacture of semiconductors and electronic appliances requires a high degree of air purity. Air conditioners may supply very pure air to the workshops, but the air thus treated is totally devoid of oxygen ions. People working in this air tire easily, do not feel well, and lose their power of concentration and ability to work, resulting in a high percentage of production rejects. In this case too, air ions should benefit the workers.

In certain industries friction of machinery parts generates large static charges which interfere with work, and which might be neutralized by air ions, all having the same charge.

* Effluvial point-discharge precipitators remove dust at a rate 15 times higher than the working rate of ordinary electrostatic precipitators (A. L. Chizhevskii, N. D. Kiselev, and S. A. Prechistenskii).

Regular campaigns should be initiated against several pulmonary diseases (such as pneumoconiosis and silicosis) induced in miners by dust. It has been proved that negative air ions stimulate the cilia of the epithelium lining the surface of the upper respiratory tract, increase mucuous secretion, and also improve the tonus of smooth muscles. Thus, these ions facilitate ejection of dust particles from the respiratory system. Positive air ions markedly inhibit these functions, and may lead to the injurious, permanent deposition of dust in the lungs, and consequently to premature invalidism. These problems should be given immediate attention by the appropriate institutes; air ionization must be introduced promptly in the mining industry, as the author has already done at the Karaganda coal basin.

OTHER APPLICATIONS OF AIR IONIZATION

We shall now briefly enumerate several other fields in which air ions generated by the effluvial ionization method may be successfully applied.

The air filtered in air conditioners leaves not only dust and microorganisms on the filters, but also all the ions initially present in the outdoor air, and consequently the conditioned air is devoid of the beneficial oxygen ions (our works of 1925–1942). Therefore, all air conditioners supplied to places of work and other inhabited premises should be equipped with special electronic air ionizers so as to invest the conditioned air with bioactive properties necessary for life activities.

At nuclear reactors, nuclear power plants, and scientific research institutes for nuclear processes a directed flow generated by electronic air ionizers may deposit dangerous radioactive dust, thus facilitating the decontamination of air in work premises. This was first revealed in Western Germany by Dr. Betke, who was inspired by our work.

With point-discharge air ionizers, finely dispersed dust of cement, asbestos, gypsium, quartz, alabaster, zinc, aluminum, etc., is deposited and entrapped more rapidly, in special dust collectors. As a result, hygienic working conditions are radically improved, and the industry saves millions of tons of valuable building material.

Lengthy investigations proved the extraordinary effect of artificial air ionization on farm animals and poultry, especially young, slowly developing ones, and on those permanently kept indoors. Ionized air leads to the increase in size and weight of animals and poultry, raises egg production, wool clips, fat content of milk, and drastically reduces disease incidence and mortality among animals. Likewise, ionized air has proved to enhance the vigor of seeds, and increase their germination rate and their yields.

In inhabited premises the concentration of air ions tends to fall abruptly; the deionized air adversely affects the human organism, leading to loss of immunity and premature senility. For the benefit of public health, air ionization should be introduced first in schools, hospitals, sanatoria, children's institutions, administrative buildings, theaters, movie theaters, etc., and at a later stage, also in residential houses; inhabited premises should be supplied with ionized air in concentrations equal to that found in country air.

This list is far from complete. Each year air ionization finds increasingly wider application throughout the world.

It should be mentioned that the electronic apparatus for air ionization can work for many years without repairs, and its electrical consumption does not exceed that of an ordinary electric light bulb.

SUMMARY AND CONCLUSIONS

In the last decades, significant phenomena, directly related to the subject under consideration, have been reported. It has been found that identical therapeutic effects were achieved by both certain physical agents and certain polymer molecules in the treatment of many severe pathological states.

The manifold effect of physical (electric) factors and of large organic molecules may be explained by the activity at the molecular and even the electron level. The organism is penetrated by either the pulsed solar photon stream and oxygen ions of the air, or by certain polymer molecules. Their electric and magnetic fields and their electric and electromagnetic energy then act upon the electric and magnetic fields and energy of the electrons of the excited molecules and atoms contained in the pathologically changed protoplasm and structural elements of the cells, tissues, and organs.

The electric and magnetic phenomena observed in ions and in high-molecular organic compounds have a common property which, although unexplained, is applied in treating numerous diseases of different etiologies. Moreover, it must be admitted that it is neither the different chemical elements nor their molecules which are specifically effective from the medical point of view, but rather the electrical fields and ions produced by the dissociation of these substances when dissolved in the fluids of the living organism.

This does not imply that the biochemical reactions are insignificant. It means, however, that more attention must now be directed toward such physical phenomena as electric and magnetic fields and the energy of electron excitation which have heretofore been neglected. Great theoretical advances have been made in the modern biological and medical sciences, heralding an incomparable increase in their practical value. Quantum mechanics might be instrumental in elucidating the most basic physiological or molecular physicochemical processes.

The USSR spearheads the field of modern engineering, rocket dynamics, and space flights. Physicomathematical sciences in the USSR are developing at a remarkable pace. Rapid solution of the problem of air ionization may prove to be of tremendous value in improving the health of the Soviet people by harnessing the powerful natural agent of electricity to the struggle for human health. Large-scale introduction of air ionization in new buildings, factories, schools and children's institutions, hospitals, clinics, sanatoria and rest homes, places of entertainment, dwellings, etc. (i. e., the overall development of electrical resorts) might raise the standard of health and longevity in the USSR and increase the productivity

of labor. It is regrettable that we still lack a coordination center for scientific research laboratories fully equipped to implement an extensive research program of air ionization, and to facilitate the prompt introduction of the research results in the national economy of the USSR.

Organization of such a laboratory is of major importance now, when literally hundreds of scientific research laboratories and institutes engaged in studies of the biological and industrial applications of air ions have emerged in many European and American countries. The First International Conference on Air Ionization took place in Philadelphia (USA) in October 1961. The most prominent scientists (Prof. Langevin, Prof. J. Worms, Prof. I. Kornblueh, Prof. A. Krüger, Prof. U. Pontoni, Prof. G. Piccardi, Dr. A. Denier, and many others) discussed the further development of methods for the artificial ionization of air, first devised in the USSR as early as 1918.

REFERENCES

CHIZHEVSKII, A. L. Aeroionifikatsiya v narodnom khozyaistve (Air Ionization in the National Economy), pp. 1–758. Moskva. 1960. (Pages 663–756 list basic literature on the subject, some 1,400 titles, in many languages.)

B.D. Vasil'ev

ATMOSPHERIC AIR, LIFE, AND THE BLOOD

The life of highly organized animals and man is intimately linked with the intake by the organism (via the blood) of atmospheric oxygen at a certain partial pressure. It is the air—blood system which is primarily responsible for the very existence of highly organized life. Chizhevskii revealed a remarkable correlation between the number of oxygen molecules passing through the blood vessels in the lungs during a single inhalation, and the number of hemoglobin molecules in the erythrocytes passing through the capillary network of the lungs in the same time period. The air—blood system proved to be tuned with mathematical precision. This tuning developed during the hundreds of thousands of years of evolution.

Further studies of the circulatory system, such as the assimilation and transport mechanism led the same author to conclusions of extraordinary importance for understanding, from the metabolic aspect, the part played by the dynamics and kinematics of the red blood corpuscles in the blood vessels.*

Chizhevskii was the first to consider the subject of the spatial distribution of erythrocytes in human blood vessels. The bulk of the blood consists of erythrocytes shaped as circular biconcave disks. Their diameter is 7 to 8 microns and their thickness approximately 2 microns.

A drop of blood viewed under the microscope reveals a large number of erythrocytes with occasional white blood cells (normally one leukocyte per 714 erythrocytes). Among the randomly distributed cells, the erythrocytes occasionally appear to stick together, lying one upon the other (completely or partially). These formations are especially well preserved in wet preparations. They are known as rouleaux (coin rolls) because they resemble rolls of coins.

The erythrocytes carry out most vital functions, such as gas exchange, transport of protein-breakdown products, immunological processes, regulation of the ionic composition of plasma and of the osmotic and acid-alkali equilibrium, adsorption of toxins and drugs, etc. In human blood, the total surface of erythrocytes (through which metabolism is carried out) reaches approximately 3000 m^2.

The spatial distribution of erythrocytes in the bloodstream has been mathematically analyzed by Chizhevskii, who demonstrated that at a normal count (5 million/mm^3), the erythrocytes must congregate in symmetrical formations, with their concave sides facing one another. Any other arrangement would drastically reduce their normal concentration per unit

* Chizhevskii, A.L. Strukturnyi analiz dvizhushcheisya krovi (Structural Analysis of the Circulating Blood). — Moskva, Izd. AN SSSR. 1959.

blood volume, while an entirely random distribution would allow for only 2 million erythrocytes per mm^3. Thus, in the normal organism, the symmetrical formations of erythrocytes within the blood vessel must be strictly maintained. This strict arrangement is disrupted by various diseases. In anemias a semirandom or even random distribution of erythrocytes may be expected in the bloodstream.

The mathematical evidence of an ordered spatial distribution of erythrocytes in the normal bloodstream, and the tremendous significance of this phenomenon for the understanding of many blood functions of utmost importance led Chizhevskii to substantiate his mathematical deductions by actual blood preparations. He focused his attention on the rouleaux, a seemingly negligible and well-known appearance in blood smears, daily puzzling tens of thousands of laboratory technicians, physiologists, and physicians throughout the world. Only clinicians had noticed that complete absence of these rouleaux in the blood indicated a serious condition of the patient. Once, while examining a blood smear, Chizhevskii noticed that in certain fields the rouleaux displayed a parallel arrangement; this had been overlooked by hematologists.

Chizhevskii questioned whether these erythrocyte chains might not be remnants of the characteristic spatial blood structures as the blood flows through the vessels, and which disintegrate, almost completely, as soon as the flow has been stopped, i.e., when the blood has been removed from the body. The parallel arrangement of the erythrocyte chains in certain fields of the smear suggested their similar arrangement within the blood vessels. On the basis of this assumption a most thorough experimental investigation, theoretically very intricate, was conducted, involving several years of hard work. Thousands of blood preparations were examined, hundreds of analyses performed, new research techniques developed, and equations evolved, expressing the dynamics of blood corpuscles. The result was the experimental discovery of the dynamic structure of the flowing blood corpuscles in the vessels, and the devising of a mathematical model of this flow.

The course of blood plasma through the vessels complies with the laws of hydrodynamics. It has a laminar, telescopic character, whereby the peripheral, cylindrical plasma layer flows at a slower rate than the inner layers. The velocity of plasma layers increases parabolically from the periphery toward the axial zone. The erythrocytes caught between layers flowing at different rates turn so as to achieve the most streamline formation, i.e., so as to afford minimum resistance to forward movement. Consequently, erythrocytes roll on their narrow edge in the bloodstream, conforming to the laws of hydrodynamics. An erythrocyte caught between layers flowing at different rates assumes a radial position, and acquires a rotary motion around its own axis; it rolls within the vessel like a wheel. The number of erythrocytic revolutions was calculated for certain vessels. In normal concentrations the radially arranged rolling erythrocytes draw near one another with their concave sides, forming a ring, similar to a vortex, which obeys the law of a gyroscope (*Figure 1*).

The lumen of a medium blood vessel is filled with such vortical erythrocyte rings, whose fragments are known outside the body as rouleaux. The forward speed of these rings along the vessel is not uniform, but increases from the periphery toward the axial zone of the vessel. The

erythrocytes moving near the vascular axis pass through the body more frequently than those rolling along the periphery of the vessel.

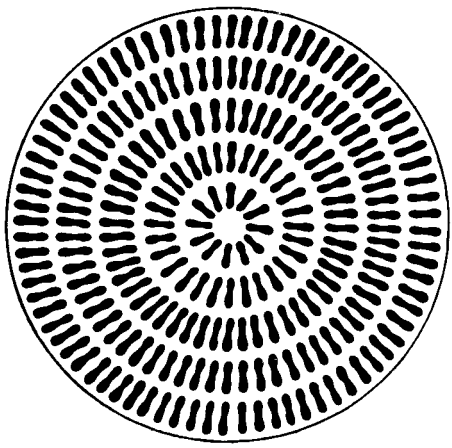


FIGURE 1. Orthogonal section of a blood vessel (diameter, 75 microns). The erythrocytes congregated in rings advancing parabolically and rotating vortically.

It was established, first theoretically and later experimentally, that the erythrocytes advancing at high speed have the smallest diameter. Hydrodynamic factors also affect the distribution of erythrocytes, according to size, in the lumen of blood vessels. The oldest and at the same time the largest erythrocytes rolling along the periphery are readily taken up and destroyed at the end of their "active life" by the reticuloendothelial cells lining the vessels. This mechanism must function continuously, because every second, millions of erythrocytes enter the bloodstream, while millions of others are withdrawn.

The radial-annular systems partially disintegrate where the blood vessels branch, but, as demonstrated by calculations and experiments, they are soon restored by hydrodynamic, electrical, and magnetic factors. Thus, the dynamic organization of blood constantly tends to reestablish its spatial pattern.

It appears that the strict time-spatial subordination of the morphology of the flowing corpuscles is intimately linked with the biochemical functions of the blood, and the complex metabolic processes. This subordination determines the steady work of the "donor" and "receptor" system of metabolites, and is under continuous control and regulation by the nervous system. The most important tissue of the organism — the blood — far from being a "confusedly running" "chaotic crowd" of corpuscles is strictly regulated in both structure and biochemical functions.

Chizhevskii experimentally substantiated his theory and his mathematical calculations by pumping blood under pressure through thin-walled glass capillaries of various diameters (at different rates of flow and with

different concentrations of erythrocytes). He was the first to observe under the microscope the amazing pattern of the spatial-dynamic phenomena in flowing human blood: orientation of the erythrocytes in the plasma flow, their rotation around the axis, the interaction between individual erythrocytes, formation and rotation of the erythrocytic rings, the telescopic movement of the rings, the hydroscopic effect of erythrocytes, and other most interesting phenomena. The experimental technique made possible the visual counting of the erythrocytic revolutions around their axes per unit time in relation to the rate of plasma flow, thus confirming the theoretical calculations. The leukocytes roll along the walls of the vessel, at the periphery of the bloodstream, always ready to defend the body. These phenomena were studied in both normal and pathological blood.

The clinical laboratories continue to examine "dead" blood in drops or smears. Chizhevskii laid the foundation for the structural analysis of blood in its dynamics, and demonstrated that flowing blood displays remarkable new properties which require further, thorough studies. He designated this branch of science dynamic hematology.

A system of electric charges covers the erythrocyte's surface. Experiments have demonstrated that inhalation of negative air ions stabilizes the erythrocytic system, while inhalation of positive air ions unloads the erythrocytes and accelerates their sedimentation (as proved by ESR tests). In the course of the rotation of erythrocytes, their electric charges generate convection currents, i.e., each rotating erythrocyte must be considered a magnet. Calculations revealed the remarkable fact that the electric, magnetic, and hydrodynamic forces acting in blood are of the same order of magnitude. Therefore the radial-annular erythrocytic structures should be regarded as a strictly regulated elastic system occurring in dynamic equilibrium and maintained throughout the pulse wave.

The erythrocytes repel one another as a result of their identical electric charge. This repulsion is promoted by the vortices formed between the erythrocytes in the course of their rotation. Consequently, the erythrocytes are prevented from sticking together, thereby impeding formation of thrombi which might plug the blood vessel and endanger the organism. The magnetic fields between the erythrocytes are symmetrically arranged and stable in the radial-annular structures. The erythrocytic rotation around their own axis and the above-mentioned vortices assist in maintaining the required rate of metabolism.

The discovery of the dynamic structure of the blood represents the second major stage in the physiology of blood circulation, after that of the circulation itself. It took more than 300 years of scientific development to discover the amazing spatial structure of the blood flowing through the vessels.

The discovery of blood circulation opened a new era in biology and medicine. The discovery of the dynamic microstructure of blood also bears tremendous consequences for the biological and medical sciences. Pathological processes are reflected in the "body's mirror"— the blood— distorting its physicochemical functions and changing its geometrical structure. Study of the blood by means of special techniques may lead directly to more accurate diagnoses and may possibly even break new roads toward appropriate therapy.

Chizhevskii's monograph is permeated with mathematical analysis, and its details are only within the reach of biophysicists and biologists who are acquainted with higher mathematics.

In conclusion, we must express our wish that Chizhevskii's discovery be further studied and implemented in the USSR.

REFERENCES

ARINKIN, M. P. Klinika boleznei krovi i krovetvornykh organov (Clinical Aspects of Blood Diseases and of the Hematopoietic Organs), Moskva. 1928.

CHIZHEVSKII, A. L. Deistvie ionizirovannogo vozdukha na krov' (The Effects on Blood of Ionized Air). — Trudy TsNILI. Voronezh. 1933.

CHIZHEVSKII, A. L. O metodike izmereniya elektricheskogo zaryada krovi (Methods for Measuring the Electrical Charge of Blood). — Ibid. 1934.

CHIZHEVSKII, A. L. Elektricheskie kharakteristiki krovi (Electrical Characteristics of Blood), Moskva. 1941.

CHIZHEVSKII, A. L. Strukturnyi analiz dvizhushcheisya po sosudam krovi (Structural Analysis of the Blood Flowing in the Vessels). — Vestnik AN KazSSR, No. 12. Alma-Ata. 1951.

CHIZHEVSKII, A. L. Orientatsiya i kinematika eritrotsitov v krovotoke (Orientation and Kinematics of Erythrocytes in the Bloodstream). — Izvestiya AN SSSR, Seriya Biologicheskaya, No. 5. Moskva. 1953.

CHIZHEVSKII, A. L. Elektroreaktsiya osedaniya krasnykh krovyanykh telets (Electric Sedimentation of Erythrocytes). — Klinicheskaya Meditsina, No. 31. Moskva. 1953.

CHIZHEVSKII, A. L. Strukturnyi analiz dvizhushcheisya krovi (Structural Analysis of Flowing Blood), Monograph. Moskva. 1959.

CHIZHEVSKII, A. L. and G. K. TROFIMOV. Obrazuyutsya li eritrotsitnye monetnye stolbiki vne organizma? (Are the Erythrocyte Rouleaux Formed Outside the Body?). — Byulleten' Eksperimental'noi Biologii i Meditsiny, No. 11. Moskva. 1955.

KORZHUEV, P. A. Evolyutsiya dykhatel'noi funktsii krovi (Evolution of the Respiratory Function of Blood), Moskva. 1949.

KULAKOV, I. N. K voprosu ob elektroreaktsii osedaniya eritrotsitov (Contribution to the Electric Sedimentation of Erythrocytes). — Klinicheskaya Meditsina, No. 8. Moskva. 1953.

A.A. Peredel'skii

PENETRATING RADIATIONS AND RADIOECOLOGY

Contemporary biology has absorbed the rich inheritance of the evolutional concepts concerning the live cover of the Earth's crust— the biosphere— in its closest dynamic reciprocal influences and interactions with the chemical and physical properties of the Earth and with the cosmic factors, and later in the interactions of individual organisms and between their groups. This subject has been designated in accordance with the needs and outlook of the different theoretical and applied disciplines, such as Vernadskii's biogeochemistry, Sukachev's geobiocenology, Tansley's ecosystem, Haeckel's ecology (1866).

The last term— ecology— proposed earlier than the others, was widely adopted and ultimately designated an independent branch of science. Although its content has been repeatedly reinterpreted and distorted, it is a fairly comprehensive, expressive, concise, and convenient designation, provided it is reinvested with its original meaning. This term proved instrumental in the designation of the recently conceived /1–7/ synthetic trend in science— radioecology. This stemmed from the need for a correct understanding of the specific patterns involved in the interaction of the biosphere with the radioactive isotopes and their radiations (increasingly invading the polluting the natural environments).

The theoretical aspects of radioecology display an even higher diversity /2/, as they overlap at the intersections of radiobiology with several other scientific disciplines, such as radiation genetics, paleontology and the theory of evolution, geology, geochemistry and biogeochemistry, and hygiene. Radioecology cannot ignore the penetrating radiations arriving on Earth from interplanetary space.

This space is permeated throughout by radiations of electromagnetic waves encompassing a wide spectrum (infrared, visible, ultraviolet, X-rays, and gamma rays), and fluxes composed mainly of protons and alpha-particles but also of heavy-element nuclei (primary cosmic rays).

Cosmic rays are a very important natural source of particles because of the extremely high energy of the particles despite the very low intensity of radiation. Therefore they interact with atomic nuclei and induce essential changes in the media (such as air, water, soil, or the living tissues of organisms) through which they pass and by which they are absorbed.

In the lower layers of the stratosphere, at a moderate distance from the Earth, the primary cosmic rays penetrating the atmosphere collide more frequently with the atomic nuclei of atmospheric elements, forming new particles by splitting the nuclei of both, and producing cascading showers,

i.e., secondary cosmic radiation having soft and hard components. The soft radiation consisting of electrons, positrons, and photons is not highly penetrative, and is largely absorbed by the atmosphere, although some photons and electrons do reach the Earth's surface. The hard radiation consists of mu-mesons from which the radiation derives its extremely high penetrating power, against which neither the atmosphere, nor the hundreds of meters of the Earth's crust afford protection. Apart from these types of radiation, their transformations in the atmosphere create neutrons, protons and pi-mesons whose penetrating power is lower than that of the mu-mesons but higher than that of the photons and electrons.

Thus, all organisms inhabiting our planet throughout the innumerable generations have been and will continue to be affected by the penetrating cosmic radiations. The dose rate of this irradiation varies with the different sites on the globe and at different absolute elevations, and also depends upon the periodic and nonperiodic variations in space. Nevertheless, the average annual dose of cosmic radiation is about 0.03–0.3 rad,* according to geomagnetic latitude and absolute elevation.

Penetrating ionizing radiation of natural origin, which are independent of human activities, set up a so-called background radiation. Its yearly dose is larger than the afore-mentioned since it comprises, in addition to the ionizing activities of cosmic rays, radiations emitted through decay of a wide range of natural radioactive matter, ubiquitous in the Earth's crust (its soils, waters, atmosphere, and live and dead tissues of organisms). The main sources** of alpha, beta, and gamma rays causing air ionization are the result of radioactive decay, and produce doses ranging from approximately 45 mrad/year in sedimentary rocks to 110 mrad/year in granite.

Consequently, the organisms are exposed to penetrating radiation from outside in doses fluctuating between 48 and 410 mrad/year, and, even reaching one rad/year and more in localities particularly rich in radioactive substances. This, however, is not the only penetrating radiation to which the organisms are exposed. The radioactive isotopes disseminated in nature (see above) gradually accumulate in the various organs and tissues from the substances reaching the plants through soil and water,

* The dose of radioactive radiations is expressed in roentgen, or rad, or in thousandths and millionths of this unit. At a dose of one roentgen (1 r), $2.06 \cdot 10^9$ pairs of ions are formed in 1 cm^3 air, and 0.108 erg energy is absorbed, while 1 g irradiated water, plant, or animal tissue absorbs 83.4 erg energy. However, it is more expedient to use the corresponding unit of absorbed energy of ionizing radiation expressed in rad. A rad is equivalent to 100 erg energy absorbed by 1 g matter, Consequently, one rad corresponds to a dose of 1.12 r. One thousandth of a roentgen, or a rad, is designated respectively as one milliroentgen (mr), and one millirad (mrad), while a millionth is designated 1 μr and 1 μ rad. Preference is given to the rad unit in view of its adaptability for measuring the effects of any radiation connected with ionizing particles.

** Of the natural radioisotopes, the following are, generally, of radioecological interest: the alpha- and gamma-emitters— U^{235}, U^{238}, Ra^{226}, and Th^{232}; the alpha-emitters— U^{238} and Th^{232}; the beta- and gamma-emitter— K^{40}; the beta-emitter— C^{14}, and the alpha-emitters— Rn^{220} and Rn^{222}.

The radioactive isotopes that contaminate the natural environment (originating from the wastes of nuclear power plants and nuclear explosions) are the beta-emitters— H^3, C^{14}, P^{32}, Pm^{147}, Sr^{90}, Y^{90}, Ru^{106}; the gamma-emitters— Mn^{54}, Y^{91}, Nb^{95}; the alpha- and gamma-emitters - U^{235}, U^{238}, Pn^{234}; and the beta- and gamma-emitters— Na^{24}, Fe^{59}, Co^{60}, Zn^{65}, Kr^{85}, Sr^{89}, Zr^{95}, Pm^{147}, Rh^{103}, Rh^{106}, I^{131}, Cs^{134}, Cs^{137}, Ba^{137}, La^{140}, Ce^{141}, Ce^{144}, Pr^{144}, Nd^{147}.

and the animals through the ingested plants or bodies of other animals, through their drinking water, as well as through the air. As a result of radioactive decay, the organisms are also irradiated from within in doses amounting to approximately 30 mrad/year.

These are the small doses of irradiation to which generations of organisms have been constantly exposed over hundreds of millions of years. Clearly, if such doses would have proved injurious for the living world, the latter would have either perished, or developed certain properties, in the course of evolution, that would protect it from the effects of background radiation. Since life on Earth has existed for a billion years, it has obviously adapted somehow to the cosmic and planetary sources of penetrating radiations. Even places with exceptionally high natural radioactivity are inhabited by microbes, plants, and a variety of animals.

The study of radioactivity and of its potent and singular effects on various organisms began to develop by the turn of the century. Scientists naturally focused their attention more on ore dumps and on the already processed minerals, which contained considerably larger amounts of radioactive isotopes than ordinary soil.

The Czech scientists Stoklasa and Pěnkava published in 1932 an exhaustive review concerning the effects of uranium and radium on organisms, and describing in the light of the research achievements at that time, the character and condition of wild plants growing on such dumps or in radium-rich soils. The majority of such plants were reported to develop better and more rapidly than those in nearby plots with ordinary soils. However, unusual diseases were occasionally recorded, especially in perennial grasses, resulting in changed pigmentation of leaves, slower growth rate, and death. More recent publications indicate, although not very clearly, that in areas with high natural background radiation, plant communities may display certain properties manifest in the positive or negative selectivity of the individual plant species in such habitats. Phytogeologists can readily establish the variations in the condition and density of representatives of individual species, either from their unexpected occurrence and even predominance in the plant cover of a region, or from their complete absence in regions in which they apparently should have been included in the local herbaceous cover, according to the general conditions, and in comparison with similar but nonradioactive neighboring regions.

From the modern point of view, the discovery of the striking effects on organisms of different nonradioactive microelements (i. e., substances found in soil in minute, almost indeterminable concentrations) may be attributed to the oligodynamic geochemical action of some nonradioactive elements associated with uranium and radium, rather than to penetrating radiations. The generalizations made by Stoklasa and Pěnkava, as well as other current generalizations, fail to take into account the biologically important fact that increased radioactivity in the biosphere is accompanied with increased concentration of free ions, including atmospheric gas ions (air ions) which are inhaled.

It is well-known that the exposure of radioactive ores to light and air during their mining and transportation to concentration plants leads to their waste through erosion and deflation, resulting in areas with high background radiation. Occasionally the ore dumps in concentration plants and the waste piles near factories producing radioactive preparations also

raise the background radiation over large areas /8/. Convincing data /9, 10/ confirm that solid particles of radioactive aerosols contaminate extensive areas around working reactors. The radioactivity of water and the range of dispersion of radioisotopes discharged in water bodies together with the diluted effluents from nuclear and other industries and from scientific institutions working with radioisotopes have been reported repeatedly /11–18/. We now have fairly reliable data concerning global contamination with radioisotopes of the atmosphere, dry land, and oceans following experimental explosions of atomic and hydrogen bombs /10, 19, 20, 21, 22/, breakdowns of atomic reactors /10, 23/, etc.

Such contaminations have evidently been caused by the diverse activities of modern man. The dispersion and redistribution of these contaminations, apart from the losses incurred in transport, are explained by certain purely abiotic factors (such as transport by atmospheric and oceanic currents, and ion exchange in soils), as well as by some powerful biotic factors (biogeochemical and radioecological).

It should be emphasized that these biotic factors may also affect the redistribution of the radioactive isotopes that exist in nature. Thus, when radioisotopes are absorbed from superficially deposited ore layers by the root systems of plants, a considerable part of the substances finds its way to the epigeal organs. From the fallen leaves and needles, and the dead branches and stems, the isotopes are transmitted to the forest litter and plant debris of meadows, from which they are leached by atmospheric precipitations, or absorbed by the microorganisms decomposing the litter, as well as by mushrooms, various worms, insects, and other animals. It is possible that the same may happen with the radioactive excretions and carcasses of such animals, although not usually at the same site, but rather at some distance from the ore-bearing sectors. The same can also be said of phytophagous animals, including the multitude of insects, and of the insectivorous and phytophagous birds which, with their movements, flights, and migrations over the centuries could contribute to the spatial redistribution of various elements, the changing of boundaries of geochemical provinces, and the dissemination of surface radioactive ores /24, 25/.

It was experimentally demonstrated /26/ that various plants can release through root exudates some of the radioactive isotopes absorbed by any of their organs including leaves. From the soil, these radioactive isotopes are soon taken up by the root systems of neighboring plants (of the same or different species of trees or grasses), and, in the same manner, continue their migration. In this way, the initial concentration of radioisotopes is steadily lowered as a result of dispersion in increasingly larger volumes of soil, and in the biomass of the rhizosphere microorganisms, and plants. This is one type of ecological interrelationship of organisms, causing biological migration of radioisotopes.

Similar in principle, although more diversified, are the ecological paths of migration, redistribution, concentration, and dispersion of radioisotopes released from industrial and military sites, contaminating the surrounding areas— their soils, plants, water bodies, and atmosphere. The paths of ecological food chains have been studied more thoroughly and can be followed more easily. Thus, radioactive substances migrate from the soil through plants to man. A more intricate chain involves the passage of radioisotopes from plants to animals, and then to man via meat

and dairy products. In other known chains, the radioisotopes reach man through predatory and nonpredatory fishes that had consumed radioactive fishes, plants, minute aquatic organisms (plankton), periphytic organisms from silts, and benthos, which, in turn, had fed on organisms with stored-up radioactivity, or had extracted the radioisotopes directly from the water or from organic substances.

Although this concept is almost classical, it cannot encompass all actual possibilities since in addition to the alimentary path there are also other different means of uptake of radioisotopes by organisms in any ecological chain. For instance, radioisotopes may be taken up by direct consumption of contaminated water, or of fish which have drunk it or passed it through their gills, or from contaminated water (including atmospheric precipitation) that has moistened the surface of leaves or of animals, or from depositions on the body and inhalation of radioactive aerosols. The food chains in nature are usually much more diversified and complex than outlined in the examples mentioned above, and may vary tremendously for the same organism according to different conditions, season, developmental phase, physiological state, etc. Depending on season and other conditions, many fishes and terrestrial animals may also vary abruptly, by expanding or narrowing down the specific food composition and other sources of nutrition, as well as by altering the frequency of their feeding. These changes complicate, sometimes extremely, the outline of their ecological, i.e., radioecological interrelationships /27/.

It should be emphasized that the biological absorption, incorporation, and elimination of radioactive isotopes are closely correlated, with the chemical nature and state of the substance with which the isotope is combined, the physical and chemical conditions of the medium in which the organism encounters the isotope, as well as with the constitutional properties of the organisms themselves.

These factors must be fully taken into account if we are to assess correctly the recently evolved concept of discrimination factors, and the raging debates on the extent of danger from global radioactive fallout, especially of Sr^{90}, following thermonuclear tests /28–33/.

It is clear that detailed, specific studies of radioecological processes cannot be an aim in themselves. However, whereas the general principles of radioecology may be readily implemented, each specific inquiry made by practical workers will require fairly detailed surveys of the actual local microbial ecology, or of the ecological aspects of the plant or animal populations, since these largely determine the accuracy and feasibility of the respective practical suggestions. This statement can be readily illustrated by several examples.

At present, we are faced with the acute problem of decontaminating large areas of arable land contaminated, in varying degrees, by radioactive products with prolonged half-lives. Obviously, removal of contaminated topsoil (e.g., a layer approximately 5 cm thick) from large areas is not feasible. It was suggested, that the contaminated area be plowed under to a depth of 70 cm, thereby burying the contaminated topsoil /34/. It was claimed that this would prevent radiation, as well as scattering of the various radioisotopes by winds or their eluviation by rainwater. However, the principal aim was to prevent any contact between the assimilating root systems of the crops and the contaminated soil layer, thus preventing

the undesirable build-up of radioisotopes in the plants, i. e., in the food, fodder, and industrial products.

This suggestion would appear to be quite reasonable, although it would involve expensive work with powerful tractors and special plows. However, ecologists might still question the expediency and effectiveness of this method of decontaminating farmlands. Decontamination implies removal and burial of radioactive isotopes, whereas here, the latter remain essentially in place in the soil volume, i. e., in the biosphere, in the body of a specific structure with its particular processes. Capillary forces, for example, raise the water together with its solutes to the upper soil horizon. It is known that certain dangerous radioisotopes are fairly hydrotopic, and are only partially fixed by the soil in ion-exchange reactions. In 1960 and 1961, at meetings of the Moscow Society for Natural Research we reported /64/ pronounced migrations of radioisotopes (Sr^{90}, Ca^{45}) together with the circulating capillary soil moisture (in loams and sands). The isotopes rise with the moisture toward the evaporating soil surface, where they concentrate within a relatively short time in the topmost soil layer (0.5-mm thick). Furthermore, the root systems of some cultivated plants may penetrate to considerable depths, especially in nutrient-deficient soils. Moreover, the widespread weeds with their deep-reaching roots will carry the buried isotopes from the bottom to the top soil horizons. This is further aggravated by the possible radioisotope migration from one species to another through their root systems. We have established /35/ that animals living in the soil contribute to the assimilation of radioisotopes by plants by spreading the elements not only by way of biological migration but also mechanically by burrowing in the soil, throwing the soil up from the deeper to the surface horizons, etc. As a result, radioisotopes with long half-lives, far from being buried for extended periods of time, might be expected to spread and continuously contaminate the upper and lower soil horizons, as well as the crops. Consequently, the method of primary deactivation described might prove unsatisfactory, necessitating repeated decontamination of the same area by different means. On the other hand deep plowing-under might prove effective in areas contaminated by isotopes with short half-lives. Within certain limits it might also prove safe in special circumstances, such as in soils devoid of plant cover and with a poor fauna. In any event, this method should be evaluated by long-term investigations and experiments.

Another method of deactivation, based on the ability of plants to store up radioisotopes in their aerial parts, appears to be more promising. The land should be sown for several consecutive years with specially selected herbaceous mixtures. These should be mown and the hay burnt in field incinerators provided with special traps for radioactive ash and aerosols; finally, the radioactive ash should be buried in concrete containers. Such a technique might greatly facilitate decontamination of extensive agricultural areas.

This method may be suitably modified in each case, according to the agricultural practices and ecology of the different plants in the various soils, and the reaction of plants and soils toward various isotopes /36–41/. It was demonstrated, for example, that in light sandy loamy soils the build-up of certain radioisotopes (including Sr^{90}) by any plant species, and especially by some legumes, is much more intensive than in light clayey

soils or in heavy clay soils. The difference has been tentatively explained by the mechanical make-up and other properties of the various soils.

This explanation seems inadequate. Attention is drawn to the fact that the microbial population is denser in heavy soils than in light ones; consequently the absorption of isotopes by competing microorganisms is more intensive in the heavier soils.

The part played by soil microorganisms in the assimilation and fixation of radioisotopes was recently reconfirmed by Krasil'nikov /42/. The soil fauna (such as worms) is also richer in heavier soils. As mentioned earlier, worms facilitate the assimilation of isotopes by plants /35/. It should be recalled that earthworms have l i m e (o e s o p h a g e a l) g l a n d s which accumulate calcium from the soil and then release it; thus, earthworms are most effective in the translocation of calcium, and its cycle in soil. These glands may also appropriately be called s t r o n t i u m g l a n d s, and special attention should be focused on the role of earthworms in the cycle of radioactive strontium and in soil contaminated with the latter. There are several other conceivable circumstances, such as strong fixation of isotopes by soils rich in organic matter, different degrees of fixation according to the pH of the soil, and the presence in soil of cations or anions chemically similar to those of the isotope. Consequently, the degree of assimilation by plants of isotopes from the soil is the resultant of several factors, and the role of these factors must be well understood in order to obtain positive results with the technique of sowing selected grasses and their subsequent removal by mowing, in the process of decontaminating farmlands.

The method under consideration will require further modifications, since radioisotopes are prevented by other factors from remaining fixed in the soils; for instance, earthworms and various burrowing soil-inhabitants transfer radioisotopes, and the root systems gradually contaminate the neighboring, originally clean soils. This process can probably be stopped fairly easily by sufficiently deep ditches (with embankments facing the contaminated side) dug along the boundaries of the contaminated area so as to prevent migration of the fauna, spreading of radioisotopes from root systems and soil solutions. This technique seems more effective than the plowing of a wide strip along the boundaries of the contaminated sector, in order to destroy its plant cover, followed by the depositing of sand, gravel, or slags for obstructing the spreading of roots and migration of soil animals and solutions. After decontamination it will certainly prove easier to fill the ditches with the soil from the embankments, and level them, than to remove the sand, gravel, or slag which will then interfere with the tilling of the field.

Some authors have recommended liming of the soils, or addition of other calcium or potassium compounds for stopping the translocation of radioactive strontium in plants /41/; we, however, regard this method as invalid. Instead of effecting a rapid deactivation, as can be achieved by mowing, liming will only protract deactivation over a longer period. Strontium will nevertheless migrate into plants and then to farm animals and humans, whereby the build up of undesirable doses will inevitably occur, although over a longer period than without liming. Moreover, liming will mainly affect assimilation of strontium but not of other radioisotopes. This technique is ineffective in soils rich in calcium. Finally,

radioisotopes are assimilated by plants not only from the soil— they can also be assimilated through the foliage.

There is also the possibility of treating the soil with petroleum or bitumen, thus forming complexes that bind the radioisotopes, preventing them from penetrating into the plants.

Radioecologically, contamination of river floodplains is heaviest not only downstream from nuclear power plants, but generally over the entire floodplain, although to a lesser extent. Floodplains are regions of annual deposition of soil particles washed by snowmelt from extensive land areas, and therefore concentrate radioisotopes washed off from extensive areas. The most valuable hayfields, pastures, plantations, and fields of present-day floodplains may sometimes conceal greater radioactive danger than the watersheds.

In general, the geomorphological elements of the Earth's surface which are so important for the understanding of ecological properties are also important for the understanding, forecast, and control of radioecological phenomena. Distribution of radioactive fallout from the atmosphere is largely dependent upon the local geomorphology and winds.

Usually, larger amounts of fallout settle on elevations than on depressions. This difference has been clearly demonstrated, particularly in the neighborhood of nuclear power plants /9/. In order to reduce the radioecological danger in floodplains, it is possible to stop the discharge of radioactive wastes into rivers and river floods, and to control flooding and direct inundation by snowmelt through effective drainage; floodplain soils will have to be decontaminated by techniques similar to those tentatively suggested for other sectors.

Forest ecology involves theoretical and practical problems which are both complex and difficult. The forest is a very complex phenomenon and radioecological studies of it have scarcely begun. It is quite understandable that owing to the vast area of foliage, branches, tree trunks, shrubs, the herbaceous and moss cover, litter, etc., the forest is probably an efficient trap and accumulator of radioactive isotopes from the contaminated atmosphere. The biogeochemical cycle of matter in the forest is vast and diversified and must also involve the radioisotopes. It is important to be able to understand and predict what will happen to radioisotopes in the different components of living (and sometimes of dead) forests; it is necessary to foresee the degree of radioactive danger represented by the contaminated forest as a whole, and also of its products, which include food (mushrooms, berries, game), timber, other commercial wood, and firewood (whose ash might be radioactive). A large, essential task is the investigation of the effect of radioactive contaminations on the various forest animals ranging from insects and small fur animals to large animals such as elks and bears, as well as to birds. In addition we cannot ignore the highly specific forms of concentration, and dissemination of radioisotopes by migration of billions of windborne seeds and insects, and thousands of birds and beasts as they make their way into and out of the forest.

Methods of alleviating, stopping, and isolating these radioecological processes must be found in order to decontaminate the living or dead forest. The simplest suggestion is that such a forest together with the adjacent protective zone should be declared a forbidden area for as long as

required to achieve a safe level of radioactivity by natural decay. Yet, it would seem that suitable radioecological investigations might result in more flexible policies concerning heavily contaminated forests than complete isolation, or a more severe measure of burning it in situ (whereby the large quantities of radioactive ashes and aerosols might be blown by winds over large distances). The danger of forest fires is high enough without their being started intentionally.

Because radioactive isotopes accumulate in the forest litter (from the shedding of leaves), forest decontamination is laborious and only partially successful. It involves collecting, removing, and burning the litter at suitable sites, and subsequent burial of the radioactive ash. A certain degree of decontamination may thus be achieved provided this process is repeated over a period of several years. A dead forest, however, does not shed leaves, and therefore much labor will be required for cutting, removing, and burning (in suitable locations) the heavily contaminated wood, and for burying large volumes of ash. There is no doubt that the ecological conditions will dictate the suitable techniques and their details in each specific case. In this connection, we must emphasize that the specific radioecological features of each contaminated sector should be determined individually.

Let us now analyze the role of radioecology in elucidating processes which occur in contaminated water bodies. As yet, even the most technically advanced countries continue to bury the diluted radioactive wastes from nuclear power plants in water bodies with sluggish flow and in larger rivers. This practice is most common in the USA. In the USSR /16–18/ several authors /43, 44/ have persevered in their attempts at solving the problem of decontamination of such water bodies by means of a series of interconnected reservoirs with water rich in silts, aquatic plants, and plankton. The principle is, essentially, to utilize the initial stages of the radioecological process in the contaminated waters. The authors assumed that most radioisotopes will build up in the biomass of the numerous organisms, and in the dead organic matter in the silts so that a significant degree of deactivation will already be achieved in the first reservoir; from the last reservoir in the chain, the outflowing waters will be almost completely decontaminated and might be safely used along their further course, if issuing in a river or lake. Decontamination will prove to be progressively more effective as the entire radioactivity passes into the silts and benthic sediments following the death of the aquatic organisms.

This method is certainly noteworthy and should be implemented despite its drawbacks. In the first place certain important radioisotopes (Sr^{89}, Sr^{90}, Ru^{106}, etc.) can only be extracted from water at a very slow rate. Secondly, radioecological processes, far from ending at the bottom of the reservoirs, become more intense there /2, 3/. The benthos comprises hundreds of millions of amphibian organisms, such as insect larvae, tadpoles, tritons, and others which subsist on radioactive food and leave the water body upon reaching a suitable developmental stage. Each new generation of these organisms carries over to the dry land significant amounts of radioisotopes. We have estimated and experimentally demonstrated /45/ that the dead bodies of insects originating in radioactive waters are sufficient to contaminate the surrounding dry land to the same

degree as that recorded in global contamination following nuclear tests.* Prominent, in this respect, is the contribution of insectivorous birds and water fowl which find their food in the radioactive silts. The buried isotopes are further disturbed by fish feeding at the bottom of the reservoirs. In addition, fresh-water fishes become especially dangerous for human consumption /18, 46/, while mollusks endanger the domestic animals.

We suggest that research of nuclear power plants on the decontamination of drainage should be carried out in collaboration with radioecologists, and investiations aimed at selecting the safest types of water bodies for the burial of radioactive wastes should be encouraged. It is probable that the most suitable water bodies for the purpose would be those least abundant in amphibian fauna. Water bodies of this type may also be specially designed.

From the practical aspect, knowledge of radioecological processes makes it possible to select those representatives of fresh-water and marine fauna that may serve as indicators of the radioactivity at any given time, as well as of long-standing pollution of the waters with radioactive substances.

Japanese /47/ and American /20/ investigations provide abundant radioecological data concerning the future of radioisotopes produced by nuclear explosions in the Pacific. There is no longer any doubt that in many cases fish and other oceanic food products become radioactive and unfit for consumption as a result of ecological interrelationships. The ecology of marine organisms also makes it possible to forecast the survival of the commercially most valuable animals, such as cetaceans and fishes /4/, as well as on the radioecological control of food products; substantiation of this seems unnecessary in the present article.

Radioecological substantiation is required at present, in our opinion, in order to discourage the burying of concentrated radioactive wastes at the bottom of deep depressions in the oceans and in the Black Sea. The container walls become corroded and develop leaks within a fairly short time, after which the radioactive solutions may be picked up and spread by deepwater currents. Where the presence of such currents is questionable, there is the possibility of radioactive ecological food chains (similar to those in running waters) with the progressively increasing transfer of the radioelements to the surface waters inhabited by commercially valuable fauna. In principle, biological migration of radioisotopes is possible in all areas and from all depths of the present day oceans and seas.**

The current task is to compile the actual proofs of the radioecological investigations in order to discourage and control any attempts at using marine depths for burying radioactive wastes.

* It should be emphasized that in our comparison /45/ the importance of aquatic insects has probably been grossly underrated. In fact, the global contamination of 5.4 Mc/km^2 on which we based the comparison did not result from the explosion of a single bomb, but rather from a series of explosions /19/.

** This concept was also supported by E. M. Kreps (see Izvestiya AN SSSR, seriya biologicheskaya, No. 3, pp. 321—324. 1959) on the basis of problems discussed at the 2nd International Conference on Peaceful Uses of Atomic Energy. Attention was focused on this problem by hydrologists and radioecologists of the Sevastopol Biological Station (Polikarpov and others). In recent years, they have published many interesting and important works in the Transactions of the station and in other publications. Relevant investigations have also been carried out by "Vityaz'," the exploration vessel of the Academy of Sciences.

Radioecological processes may be successfully applied for purposes other than controlling their biological danger, such as the elaboration of biogeochemical methods of prospecting radioactive raw materials, and the detection of radioactively contaminated areas /2/.

The persistent work of Cannon et al. in the USA resulted in a series of communications followed by a special monograph /48/ devoted to prospecting for uranium deposits in the upper horizons, with the aid of radiological analyses of plants, and indicator plants. (The monograph is supplemented with an album of one hundred such plants.) Successful research in this field is also being conducted in the USSR /49, 50/ and the method is being put into practice.

The suggestion was made in the USSR /25, 51/ that radioecological analyses of insects collected from any given locality might be instrumental in the prospecting and mapping of such deposits, and of areas with radioactively contaminated soil and vegetation. These analyses are simple and rapid, and can be performed on a large scale.

So far we have discussed the role of radioecology in elucidating the biological paths of concentration, redistribution, and migration of contaminating radioisotopes in nature. However, in theoretical radioecology considerable attention is given to the effect of ionizing radiations from decaying isotopes on organisms and their communities. The ionizing radiations may act without or within the organism whereby isotopes may occur in organs, cells, and individual molecules of the nucleus or protoplasm.

Results of investigations in this important field are surprisingly controversial. Without going into detail we shall only mention one view which holds that even the smallest dose of ionizing radiations damages and inhibits the life activities of organisms. Another widely adopted view maintains that the smallest doses of ionizing radiations are biologically inconsequential, that appreciable doses have a stimulating effect, and that detrimental effects appear only when the stimulating doses have been exceeded. In the dosimetric analysis of the effect of any factor in ecological, physiological, physiotherapeutic, and pharmacological practice, the second view prevails, as expressed by the Arndt-Schulz law. This view does not recognize the definitely harmful effect of any dose of ionizing radiation which is claimed by the supporters of the first view. An analysis of these different viewpoints should be approached from another angle, for example by elucidating the mechanism of action of ionizing radiations, which is beyong the scope of this paper. Here, we are essentially interested in the resistance of different organisms to radioactivity. A certain dose of ionizing radiations affects different organisms in different ways, and consequently in any association of organisms, under natural conditions as in a cultivated field, ionizing radiations disrupt previously established relationships. Thus certain species will develop more successfully than others, although not necessarily as a result of direct stimulation, but rather of the suppression by ionizing radiations of the strongly competitive organisms. These qualitative and quantitative variations in complex interacting populations — biocenoses — have been adequately demonstrated by experiments /52–54/. Disruption of the ecological relationships between the species leads to the gradual impoverishment of the biocenosis. The number of species is diminished by the disappearance of those that were both highly organized and less resistant to radioactivity. A comparative analysis of the species'

resistance to radioactivity and their capacity to incorporate different amounts of various radioisotopes in respective organs would probably also explain the impoverishment of aquatic biocenoses, and the diminished numbers and complete disappearance of certain species of fishes in natural reservoirs polluted with the drainage from experimental reactors /27/.

The intensity and frequency of hereditary changes induced by ionizing radiations have been studied by radiation genetics using extensive data. Radioecology is closely bound with population genetics, which is concerned with studies of the statistical patterns that govern hereditary transformations in large populations of different species. Transformations, induced by ionizing radiations /55/ weaken the species. The percentage of individuals in the local population (of any given species) with low viability, or none at all, increases; hence the population is reduced as a result of unfavorable environmental factors and lowered fecundity.

After a certain number of generations (especially under continuous exposure to ionizing radiations) such a population will probably disappear, and individuals of the species will no longer be found in areas contaminated by radioisotopes with long half-lives.

Thus, in the case of contamination of natural habitats by radioactive isotopes, radioecology could, in principle, predict the trend of future changes in the evolving interrelationships, and its task should include the regulation and prevention of undesirable changes.

The most undesirable and dangerous changes are modifications and mutations induced by radioactive contamination in pathogenic microorganisms, either enhancing or changing their virulence, or suppressing the activities of microorganisms vital for the fertility of soils.

New extensive research on the chronic effects on the organisms of small doses of ionizing radiations (close to the background radiation) has not yet provided sufficient data required for generalizations, so that these will have to be temporarily postponed. Moreover, such generalizations would be beyond the scope of this article.

Together with the misgivings already expressed, it should be mentioned that some scientists /56–61/ have persistently attempted to use radioisotopes in order to accelerate ripening and increase the yield of agricultural crops. In view of the stimulated germination observed in seeds soaked in radioisotope solutions, or following introduction of radioisotopes into the soil, certain authors are inclined to implement these techniques.

One suggestion /59/ calls for a mixture of uranium-fission fragments (whose optimum effective doses are fairly high) with the long-lived, and—for man—most dangerous radioisotopes, Sr^{90}, Cs^{137}, Ce^{144}, and others from wastes of nuclear reactors. Objections to this suggestion were raised by other authors /60, 61/.

It seems to us that agriculture has at its disposal many other means of improving crop yields without the addition of radioisotopes, which might lead to the systematic radioactive contamination of large arable areas, and masses of foodstuff. Such proposals do not seem very logical.

Quite differently, it has been suggested that the seeds be irradiated with X-rays and gamma rays in the laboratory, so that they would be devoid of any traces of radioactivity at the time of seeding /61/. However, even in such cases the possible danger of changes in the genetic structure of the variety cannot be ignored. This also applies to attempts at

stimulating growth and ripening of agricultural crops, increasing the yields, and improving certain components by irradiation of plants in the so-called gamma fields /62/.

SUMMARY

We have shown that ecological and, correspondingly, radioecological investigations are an absolute requirement in various cases of contamination of natural habitats and farmlands with radioactive isotopes. Theoretical radioecology delineates the solution of many practical problems and gives rise to applied radioecology (in the true sense of this word), which makes possible generalization and forecasting of phenomena occurring with the contamination of biocenosis and resulting in damage to the quality of human food and livestock fodder; furthermore it makes possible the control of these phenomena by decontamination of lands, fields, forests, and water bodies.

With a better understanding of the importance of radioecology and its potentialities in highly developed countries, such as the USSR, USA, and Great Britain, we would be free to devote ourselves to the elaboration of specific radioecological techniques aimed at weakening the undesirable biological cycles of radioactive isotopes, and to the intensification of deactivation techniques.

Biological consequences of radioactive contamination fall largely within the scope of radioecology, and we must take issue with the statement made by our most prominent representative of radiation medicine, Prof. A. V. Lebedinskii /63, p. 7/, that the science engaged in studies of the consequences of nuclear tests still lacks a name. As long as new trends in science arise in answer to practical requirements, suitable organizational systems must be derived within which radioecology may develop rapidly and efficiently satisfy mankind's current needs. Highly developed countries should organize international and national institutes and radioecological services; special courses and practical work in radioecology should be introduced in biological, agricultural, and medical courses, and the necessary textbooks and manuals should be published.

The need for trained personnel in radioecology is already acute, and specialists in this field will be needed in the next decades of the atomic century, as in addition to the existing contaminations, the peaceful uses of atomic energy will continue to saturate habitats with ecologically high levels of ionizing radiations.

When developed, radioecology will prove to be an essential tool in the coming age of interplanetary travel and in the investigation of living conditions on other planets.

REFERENCES

1. KUZIN, A.M. and A.A. PEREDEL'SKII. Okhrana prirody i nekotorye voprosy radioaktivno-ekologicheskikh svyazei (Conservation of Nature and Certain Problems of Radioactive-Ecological Relationships).— Okhrana prirody i zapovednoe delo v SSSR. Byulleten' No. 1, pp. 65–78, Izdatel'stvo, AN SSSR. 1956.
2. PEREDEL'SKII, A.A. Osnovaniya i zadachi radioekologii (Principles and Tasks of Radioecology).— Zhurnal Obshchei Biologii, Vol. 17, No. 1, pp. 17-30. 1957.
3. PEREDEL'SKII, A.A. Ekologicheskie issledovaniya deistviya ioniziruyushchikh izluchenii (Ecological Studies of the Effects of Ionizing Radiations).— Itogi nauki. Biologicheskie nauki, 1. Radiobiologiya, pp. 379–391, Izdatel'stvo AN SSSR. 1957.
4. PEREDEL'SKII, A.A. Voprosy radioekologii (Problems of Radioecology).— Priroda, No. 8, pp. 27–32. 1958.

4a. PEREDEL'SKII, A.A. Radioekologiya (Radioecology).— Voprosy Ekologii, No. 4, pp. 66–67, Izdatel'stvo Kievskogo Universiteta. 1962.

5. ODUM, E.P. Consideration of the Total Environment in Power Reactor Waste Disposal.— Proc. Int. Conf. Peaceful Uses Atomic Energy, No. 13, pp. 350–353. 1956.
6. ODUM, E.P. Ecology and the Atomic Age.— Assoc. Southeastern Biologist Bull,, No. 4, pp. 27–28. 1957.
7. ODUM, E.P. Fundamentals of Ecology, 2nd edition.— W.B. Saunders Company, Philadelphia and London, XVII+546 p. 1959.
8. STOKLASA, J. and J. PĚNKAVA. Biologie des Radiums und Uraniums. — Berlin, Verl. v. Parey, XIV+958 S. 1932.
9. PARKER, H.M. Radiation Exposure from Environmental Hazards.— Proc. Int. Conf. Peaceful Uses Atomic Energy, No. 13, p. 279 (U.S.A.). 1956.
10. Meteorology and Nuclear Energy. [Russian translation. 1959.]
11. HENDERSON, C. et al. Effects of Low-Level Radioactivity in the Columbia River.— Public. Health Repts., 71, No. 1, pp. 6–14. 1956.
12. COOPER, R.W. (1) The Abundance of the Principal Crustacea of the Columbia River and the Radioactivity They Contain. (2) A Preliminary Comparison of the Nannoplankton and Net Plankton of the Columbia River.— Nucl. Sc. Abstr., 10, No. 14, Suppl., p. 517. 1956.
13. OLSON, B.A. and R.F. FOSTER. Accumulation of Radioactivity in Columbia River Fish in Vicinity of the Hanford Works.— Nucl. Sc. Abstr., 11, No. 23. 1957.
14. DAVIS, J.J. and R.F. FOSTER. Bioaccumulation of Radioisotopes through Aquatic Food Chains.— Ecology, 39, No. 3, pp. 530–535. 1958.
15. PERKINS, R.W. and J.M. NIELSEN. Zinc-65 in Foods and People.— Science, 129, No. 3341, pp. 94–95. 1959.
16. MAREI, A.N. Sanitarnaya okhrana otkrytykh vodoemov ot zagryazneniya radioaktivnymi veshchestvami (Protection of Open Water Bodies Against Pollution with Radioactive Substances).— Moskva, Medgiz. 90 p. 1958.

17. IL'IN, D. I., A. I. PETROVA, and N. Ya. CHEPKASOVA. K voprosu o migratsii radioaktivnykh veshchestv iz otkrytogo vodoema (Migration of Radioactive Substances from Open Reservoirs). — Atomnaya Energiya, 5, No. 1, pp. 75–77. 1958.
18. IL'IN, D. I., Yu. I. MOSKALEV, and A. I. PETROVA. O nakoplenii radioaktivnykh elementov nekotorymi gruppami vodnykh organizmov (Accumulation of Radioactive Elements by Certain Groups of Aquatic Organisms). — Atomnaya Energiya, 5, No. 2, pp. 171–174. 1958.
19. Report of the United Nations Sc. Comm. on the Effect of Atomic Radiation, Gen. Assemb. Office Rec. XIIIth Sess., Suppl., No. 17, (A/3838), 228 p. New York. 1958.
20. The Effects of Atomic Radiation on Oceanography and Fisheries. — Nat. Acad. Sc. — Nat. Res. Council., Public. No. 551, IX, 137 p. Washington, D. C. 1957.
21. The Nature of Radioactive Fallout and Its Effects on Man. — U. S. Government Printing Office, p. 2065. 1957.
22. De VRIES, H. and H. T. WATERBALKE. Groningen Radiocarbon Dates. III. — Science, 128, No. 3338, pp. 1550–1556. 1958.
23. STEWART, N. G. and R. N. CROOKS. Long-Range Travel of the Radioactive Cloud from the Accident at Windscale. — Nature, 182, pp. 627–8. 1958.
24. PEREDEL'SKII, A. A. Radioekologicheskoe znachenie nasekomykh (Significance of Insects in Radioecology). — III. Soveshchanie Vsesoyuznogo entomologicheskogo obshchestva, Tbilisi. 4–9 October 1957. Synopses of Reports, 1, pp. 59–60, Izdatel'stvo AN SSSR. 1957.
25. PEREDEL'SKII, A. A. Aktual'nost' izucheniya roli pochvennykh bespozvonochnykh v sud'be zagryaznenii pochvy radioaktivnymi izotopami (The Urgency of Studying the Role of Soil Invertebrates in the Dispersion of Radioactive Isotopes in Soil). — Vsesoyuznoe soveshchanie po pochvennoi zoologii. Synopses of Reports, pp. 74–75, Moskva. 1958.
26. AKHROMEIKO, A. I. and A. V. SAVINA. Ispol'zovanie mechenogo superfosfata dlya ustanovleniya stepeni pogloshcheniya fosfornykh udobrenii seyantsami drevesnykh porod (Uptake of Phosphorus Fertilizers by Tree Seedlings Determined with the Aid of Labeled Superphosphate). — In: Sbornik rabot po lesnomu khozyaistvu. Vsesoyuznyi Nauchno-Issledovatel'skii Institut Lesovodstva i Mekhanizatsii Lesnogo Khozyaistva, No. 36, pp. 20–39. 1958.
27. KRUMHOLZ, L. A. Observations on the Fish Population of a Lake Contaminated by Radioactive Wastes. — Bull. Amer. Mus. Natur. History, 110, Art 4, pp. 283–367. New-York. 1956.
28. LIBBY, W. F. — United States News and World Report, 17 V 1957; New York Herald Tribune, 9 VI 1957. (Cited after 33).
29. LIBBY, W. F. Beneficiation of Soils Contaminated with Strontium 90: Beneficial Effect of Potassium. — Science, 128, No. 3332, pp. 1134–1135. 1958.
30. TELLER, E. and A. L. LATTER. Our Nuclear Future. Facts, Dangers and Opportunities. — Criterion Books, New York. 1958.

31. LEIPUNSKII, O. I. O radioaktivnoi opasnosti nepreryvnykh ispytanii atomnykh bomb (Danger of Radioactivity from Continuous Nuclear Tests). — Atomnaya Energiya, 4, No. 1, pp. 63–70. 1958.
32. LEIPUNSKII, O. I. O knige E. Tellera i A. Littera "Nashe yadernoe budushchee" (An Evaluation of the Book "Our Nuclear Future" by E. Teller and A. Latter). — Atomnaya Energiya, 4, No. 6, pp. 608–610. 1958.
33. KUZIN, A. M. Chem ugrozhayut chelovechstvu yadernye vzryvy (The Danger to Mankind from Nuclear Explosions). — Izdatel'stvo AN SSSR. 1959. 131 p.
34. GULYAKIN, I. V. and E. V. YUDINTSEVA. Deistvie na rasteniya i nakoplenie v urozhae radioaktivnykh produktov deleniya pri razlichnom ikh razmeshchenii v pochve (The Effect on Plants and Accumulation in Crops of Radioactive Fission Products Dispersed in Soil). — Izvestiya Timiryazevskoi Sel'skokhozyaistvennoi Akademii, 3, No. 3, pp. 53–80. 1957.
35. PEREDEL'SKII, A. A., N. A. PORYADKOVA, L. Z. RODIONOVA, and S. V. TARCHEVSKAYA. Rol' dozhdevykh chervei v ochistke pochvy ot zagryaznenii radioaktivnymi izotopami (Role of Earthworms in Decontamination of Soil from Radioactive Isotopes). — DAN SSSR, 115, No. 4, pp. 809–812. 1957.
35a. PEREDEL'SKII, A. A., I. O. BOGATYREV, and N. S. KARAVYANSKII. *Vliyanie dozhdevykh chervei i provolochnikov na pogloshchenie* rasteniyami radioaktivnykh izotopov Ca^{45}, Sr^{90} iz pochvy (Influence of Earthworms and Wireworms on the Uptake by Plants of the Radioactive Isotopes Ca^{45}, Sr^{90} from Soil). — DAN SSSR, 134, No. 6, pp. 1450–1452. 1960.
35b. PEREDEL'SKII, A. A., S. S. SHAIN, N. S. KARAVYANSKII, and G. V. NIKOLAEV. Rasseivanie radioizotopov v pochve dozhdevymi chervyami (Lumbricidae) (Dissemination of Radioactive Isotopes in Soil by Earthworms (Lumbricidae)). — DAN SSSR, 135, No. 1, pp. 185–188. 1960.
36. REDISKE, J. A. and A. A. SELDERS. The Absorption and Translocation of Strontium by Plants. — Plant Physiol., 28, pp. 594–605. 1953.
37. MENZEL, R. G. Competitive Uptake by Plants of Potassium, Rubidium, Cesium and Calcium, Strontium, Barium. — Soil. Sc., 77, pp. 419–425. 1954.
38. NISHITA, H. et al. Fixation and Extractability of Fission Products. — Soil. Sc., 81, pp. 317–326. 1956.
39. ROMNEY, E. M. et al. Plant Uptake of Sr^{90}, I^{91}, Ru^{106}, Cs^{137}, and Ce^{144} from Soils. — Soil Sc., 83, pp. 369–376. 1957.
40. GULYAKIN, I. V. and E. V. YUDINTSEVA. O postuplenii v rasteniya radioaktivnykh produktov deleniya i biologicheskom ochishchenii ot nikh pochvy (Penetration into Plants of Radioactive Fission Products and Their Biological Elimination from the Soil). — Izvestiya Timiryazevskoi Sel'skokhozyaistvennoi Akademii, 3, No. 3, pp. 81–109. 1957.
41. GULYAKIN, I. V. and E. V. YUDINTSEVA. Voprosy agrokhimii radioaktivnykh izotopov strontsiya, tseziya i drugikh produktov deleniya (Agrochemical Aspects of the Radioactive Isotopes Strontium, Cesium and Other Fission Products). — Ibid, 4, No. 1, pp. 15–34. 1958.

42. KRASIL'NIKOV, A.N. et al. Akkumulyatsiya estestvenno-radioaktivnykh elementov pochvennymi mikroorganizmami (Accumulation of Natural Radioactive Elements by Soil Microorganisms).— DAN SSSR, 120, No. 5, pp. 1135–1136. 1958.
43. TIMOFEEVA-RESSOVSKAYA, E.A. Pochvenno-biologicheskaya dezaktivatsiya vody v prudakh-otstoinikakh (Soil-Biological Deactivation of Water in Sedimentation Reservoirs).— Byulleten' Moskovskogo Obshchestva Ispytatelei Prirody, otdel biologicheskii, 62, No. 1, pp. 37–41. 1957.
44. AGAFONOV, B.M. Laboratornye opyty po biologicheskoi dezaktivatsii vody v seriyakh vodoemov-bachkov (Experimental Biological Deactivation of Water in a Series of Water Tanks).— Byulleten' Ural'skogo Otdeleniya Moskovskogo Obshchestva Ispytatelei Prirody, No. 1, pp. 97–102. 1958.
45. PEREDEL'SKII, A.A. and I.O. BOGATYREV. Zagryaznenie radioaktivnost'yu sukhoputnykh prostranstv nasekomymi, vyletayushchimi iz zagryaznennykh vodoemov (Radioactive Contamination of Dry Land by Insects Emerging from Polluted Reservoirs).— Izvestiya AN SSSR, Seriya Biologicheskaya, No. 2, pp. 186–192. 1959.
46. MAREI, A.N. Gigienicheskaya otsenka radioaktivnogo strontsiya kak faktora zagryazneniya vneshnei sredy (Evaluation of Radioactive Strontium as a Contaminating Factor of the Environment).— Meditsinskaya Radiologiya, No. 5, pp. 89–95. 1957.
47. Research on the Effects and Influences of the Nuclear Bomb Test Explosion. 1, II.— Japan Soc. Prom. Sc. Ueno. Tokyo. 1956.
48. CANNON, H.L. Description of Indicator Plants and Methods of Botanical Prospecting for Uranium Deposits of the Colorado Plateau. — Bull. Geol. Survey U.S.A., No. 1030M, 117p. Washington. 1957.
49. VINOGRADOV, A.P. Poiski rudnykh mestorozhdenii po rasteniyam i pochvam (biologicheskii metod) (Prospecting for Ore Deposits with the Aid of Plants and Soils (Biological Method)).— Trudy Biogeokhimicheskoi Laboratorii AN SSSR, 10, No. 3, pp. 3–27. 1954.
50. MALYUGA, D.P. Opyt primeneniya biogeokhimicheskogo metoda poiskov rudnykh mestorozhdenii na Yuzhnom Urale (Experimental Application of the Biogeochemical Method in the Search for Ore Deposits in the Southern Urals).— Ibid., pp. 28–59. 1954.
51. PEREDEL'SKII, A.A. and I.O. BOGATYREV. Signal'nyi metod opredeleniya po sboram nasekomykh mest s povyshennoi radioaktivnost'yu (Determination of Areas with High Radioactivity by Examination of Local Insect Collections).— IV S"ezd Vsesoyuznogo entomologicheskogo obshchestva. Synopses of Reports, 1, pp. 126–127. Moskva-Leningrad. 1959.
52. KULIKOV, N.V. Deistvie oskolkov urana na biomassu i strukturu eksperimental'nogo fototsenoza (Effect of Uranium Debris on the Biomass and Structure of an Experimental Phytocenosis).— Botanicheskii Zhurnal, 42, No. 3, pp. 377–394. 1957.
53. TIMOFEEVA-RESOVSKAYA, E.A. O skorosti podvodnogo obrastaniya v prisutstvii slabykh kontsentratsii izluchatelei (Rate of Submerged Overgrowing in the Presence of Weak Concentrations of Emitters). — Byulleten' Ural'skogo Otdeleniya Moskovskogo Obshchestva Ispytatelei Prirody, No. 1, pp. 87–96. 1958.

54. AUERBACH, S. I. The Soil Ecosystem and Radioactive Waste Disposal to the Ground. — Ecology, 39, No. 3, pp. 522–529. 1958.
55. STONE, W. S. and F. D. WILSON. — Genetic Studies of Irradiated Natural Populations of Drosophila. II, 1957 tests. — Proc. Nat. Acad. Sci., 44, No. 6, pp. 565–575. 1958.
56. ZHEZHEL', N. G. Vliyanie estestvennykh radioaktivnykh veshchestv na urozhainost' sel'skokhozyaistvennykh rastenii (Effect of Natural Radioactive Substances on the Yields of Agricultural Plants). — Sessiya AN SSSR po mirnomu ispol'zovaniyu atomnoi energii 1-5 VII. 1955. Zasedanie otdeleniya biologicheskikh nauk, pp. 149–161. Moskva, Izdatel'stvo AN SSSR. 1955.
57. VLASYUK, P. A. Vliyanie malykh doz ioniziruyushchikh izluchenii na sel'skokhozyaistvennye rasteniya (Effect of Small Doses of Ionizing Radiations on Agricultural Plants). — Trudy nauchnoi sessii, posvyashchennoi dostizheniyam i zadacham sovetskoi biofiziki v sel'skom khozyaistve, pp. 11–38. Moskva, Izdatel'stvo AN SSSR. 1955.
58. DROBKOV, A. A. Perspektivy ispol'zovaniya radioaktivnykh elementov v sel'skom khozyaistve (Speculations on the Use of Radioactive Elements in Agriculture). — Vestnik Sel'skokhozyaistvennoi Nauki, 3, No. 7, pp. 86–94. 1958.
59. TIMOFEEV-RESOVSKII, N. V. et al. O deistvii slabykh doz ioniziruyushchikh izluchenii na rost i razvitie rastenii (Effect on the Growth and Development of Plants of Low Doses of Ionizing Radiations). — In: Sbornik rabot Laboratorii biofiziki Ural'skogo filiala AN SSSR, No. 1, pp. 129–201. 1957.
60. PORYADKOVA, N. A. Metodika i rezul'taty nekotorykh opytov po radiostimulyatsii rastenii (Methods and Results of Experimental Radiostimulation of Plants). — Biofizika, 1, No. 7, pp. 597–615. 1956.
61. KULIKOV, N. V. Povyshenie urozhainosti nekotorykh ovoshchnykh kul'tur s pomoshch'yu slabykh doz ioniziruyushchikh izluchenii (Yields of Certain Vegetables Increased by Low Doses of Ionizing Radiations). — Byulleten' Ural'skogo Otdeleniya Moskovskogo Obshchestva Ispytatelei Prirody, No. 1, pp. 67–78. 1958.
62. BRESLAVETS, L. P., N. M. BEREZINA, and G. I. SHIBRYA. Dlitel'noe deistvie malykh doz gamma-luchei na nekotorye sel'skokhozyaistvennye rasteniya (Prolonged Influence of Small Doses of Gamma Radiation on Certain Agricultural Plants). — Biofizika, 1, No. 6, pp. 555–563. 1956.
63. LEBEDINSKII, A. V. O vrede ispytanii yadernogo oruzhiya (The Damage Involved in Testing Nuclear Weapons). — In: "Sovetskie uchenye ob opasnosti ispytanii yadernogo oruzhiya," pp. 6–28. Moskva, Atomizdat. 1959.
64. (1) PEREDEL'SKII, A. A. and I. O. BOGATYREV. O pererasprede-lenii radioaktivnykh izotopov v pochve pod vliyaniem kapillyarnykh sil (Redistribution of Radioactive Isotopes in Soil by Capillary Forces). (2) PEREDEL'SKII, A. A. and G. V. NIKOLAEV. Radioekologicheskoe znachenie vynosa radioizotopov v poverkhnostnye sloi pochvy v rezul'tate tsirkulyatsii vody (Radioecological Consequence of the Emergence of Radioisotopes in the Superficial Soil Layers Owing to Water Circulation). — Byulleten' Moskovskogo Obshchestva Ispytatelei Prirody, otdel biologicheskii, 57, No. 6, pp. 136–138. 1962.

A. V. Krylov

MAGNETOTROPISM IN PLANTS

When the life activities of plants are studied in conjunction with various environmental factors, no attention is usually given to the geomagnetic field.

However, it seemed that under certain conditions the Earth's magnetic field must influence these life activities. Such an assumption was based on the presence of magnetic properties in all substances, as revealed by modern physics /1/. Consequently, the individual organelles, cells, tissues, organs, and the organism as a whole must possess magnetic fields The energy of the molecular bonds determining the chemical reactivity of substances is a manifestation of the magnetic properties of matter, and should thus change with variation in these properties. This is also reflected in the metabolism. The magnetic properties of a substance may vary according to temperature, intensity of external the magnetic field, orientation with respect to the lines of force of such a field, etc.

The chemical reactions between substances, accompanied with changes in their magnetic properties, generate electrical potentials, i. e., biocurrents. The ensuing biocurrent will itself affect the magnetic properties of the matter. In the process of life activities an organism generates an electromagnetic field which is an inseparable part of the living system. It may be assumed that the magnetic properties of matter are the cause of polarity, which represents the most general feature of living matter.

Polarity both reflects and determines the definite character of the organism's metabolism. Any change in the magnetic properties of a substance, and consequently changes of polarity, must be reflected in the life activities of the organism.

The physical basis, determining the continuous transformations of substances in the organism is represented by uncompensated (asymmetric) electromagnetic forces. The continuous movement of protoplasm may be regarded as the result of asymmetric polarity.

The relationship between growth rate and intensity of plasma movement has been established. The rate of movement is strongly affected by the presence of oxygen, which, it is interesting to note, possesses marked magnetic properties. The primary value of oxygen for life processes possibly derives from its magnetic properties. The presence of oxygen in a living system may strongly affect its electromagnetic state, altering the asymmetry of its polarity. Changes in the chemism of the metabolism may increase or decrease the asymmetry of polarity, or shift its sign toward positive or negative values. Reversal in the sign of polarity must change the direction of biochemical processes. It may be stated that the rate and

character of interactions, and consequently the growth and development of organisms, will be primarily determined by the polarity.

In connection with the significance of polarity for life activities of plants we should mention the experiments on the effect of electrons upon growth of unfertilized ovaries of tomato plants.

When the experimental ovaries of the tomato plants were ready for fertilization, they were treated with electrons from radioactive phosphorus, P^{32}. Development of the unfertilized ovaries appears to have been induced by their exposure to negatively charged particles. The experiments revealed that the asymmetry of polarity was increased toward negative values under the effect of the electrons. This change in the asymmetric polarity indicated the conditions required for the onset of growth processes.

While setting up our experiments on the effect of geomagnetism on the life activities of plants, we intended to utilize that change in the magnetic properties of the individual components of the living system that might arise from the different orientations of the organism with respect to the direction of external magnetic fields. We therefore assumed that the maximum (readily detected) change in the life activities of plants will occur when the external magnetic field is applied during the initial period of life processes, i. e., before the tissues assume a stable state of polarity, and before the various biochemical processes are fully developed, their rates and relationships being marked by continuous changes. With these considerations in mind we chose plant seeds as the appropriate object of investigation.

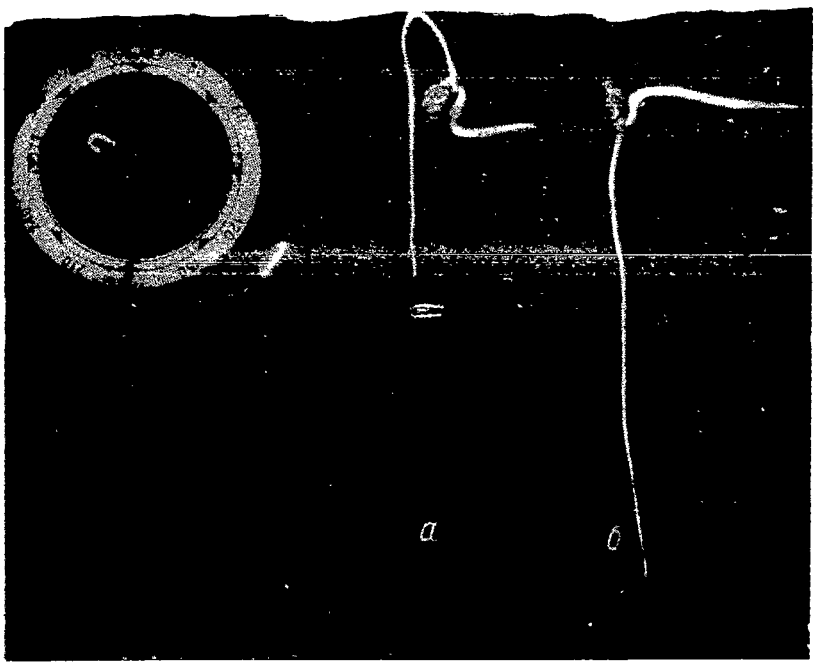


FIGURE 1. Maize sprouts germinated from seeds placed with their radicles differently oriented with respect to the geomagnetic poles: a–toward the North Magnetic Pole; b–toward the South Magnetic Pole.

Dry seeds were variously arranged with respect to the geomagnetic field. At the time of swelling and germination, the biochemical processes unfolded seeds with some of the radicles facing the South Magnetic Pole of the Earth, and others the North Magnetic Pole. The experiments were conducted in the dark at temperatures ranging between 18 and 25°. The seeds were germinated in moist glass chambers. In some experiments the seeds were placed on evenly moistened filter paper, while in others they were provided only with the humidity of vapor.

Experiments on seeds of the maize variety "Voronezhskaya-76" (Figure 1) indicated that seeds with their radicles toward the South Magnetic Pole germinated somewhat earlier than those facing the North Magnetic Pole. The roots of these sprouts grew toward the South Magnetic Pole. The growth of both roots and stalks was more intensive than in the sprouts produced by seeds initially placed with their radicles toward the North Magnetic Pole. In addition to the different rates of growth of the stalks and roots, the experiments also revealed that the roots of sprouts from seeds initially arranged with their radicles toward the North Magnetic Pole bent, and proceeded to grow toward the South Magnetic Pole. In the course of this study a new phenomenon was thus revealed, which we deemed justified in designating magnetotropism /2/. Subsequently, the same phenomenon was reported by the British professor Audus who experimented with lettuce seeds /3/.

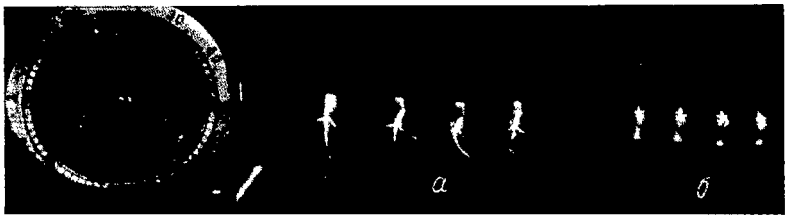


FIGURE 2. Wheat sprouts germinated from seeds whose radicles were differently oriented with respect to the geomagnetic poles: a–toward the South Magnetic Pole; b–toward the North Magnetic Pole.

It should be noted that when the experimental conditions required preliminary soaking or germination of the seeds, and these were then appropriately oriented with respect to the geomagnetic field, the effect of the latter was extremely reduced, or totally absent. This critical reaction of tumescent or germinated seeds may be explained, apparently, by the definite polarity established in seeds with their initial tumescence, even before growth is visible, and cannot be noticeably changed by the geomagnetic field. Water seems to be largely responsible for the emergence of polarity.

Numerous repeat experiments with seeds of maize, wheat, and other plants conclusively established the influence of the geomagnetic field on the germination of seeds and the growth of sprouts (Figure 2).

The effect of a magnetic field on the germination of seeds and further growth of sprouts was also studied in the magnetic field of artificial

permanent magnets. A special device was set up for these studies, consisting of two horseshoe magnets with their opposite poles facing each other. The distance between the poles could be adjusted with the aid of a special screw. The dry seeds were placed between the magnetic poles on suitable supports. The seeds were provided with moisture from the humid air in the chamber in which the experiment was set up. The seeds were germinated in the dark.

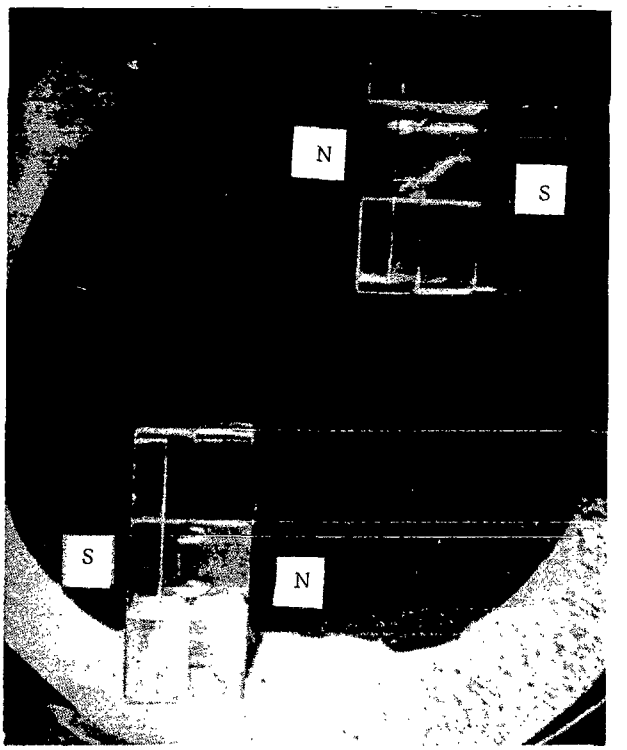


FIGURE 3. Effect of a permanent magnetic field on germination of wheat seeds and further growth of the sprouts from seeds with radicles oriented in different directions with respect to the magnetic poles: a–toward the North Pole; b–toward the South Pole. Magnetotropism is evident.

Seeds of various plants were tested in the artificial magnetic field, as illustrated in Figure 3 by germination of the wheat variety "Krasnozernaya." The wheat seeds placed in the magnetic field with their radicles toward the South Pole of the magnet germinated before those oriented toward the North Pole. From the seeds with radicles oriented toward the South Pole, stalks and roots grew more intensively, with the latter deviating sharply from the plumb line, toward the South Pole of the magnet. In seeds whose

radicles were directed toward the North Pole of the magnet, the growth of roots was noticeably retarded, and the growth of stalks less satisfactory. Similar results were obtained with seeds of maize (Figure 4), radish, and other plants. The artificial magnetic field overcame the influence of the geomagnetic field. Germination of the seeds of various plants in the artificial magnetic field confirmed the patterns previously established in the geomagnetic field.

FIGURE 4. Effect of a permanent magnetic field on the germination of maize seeds and further growth of the sprouts from seeds with radicles differently oriented with respect to the magnetic poles: a-toward the North Pole; b-toward the South Pole.

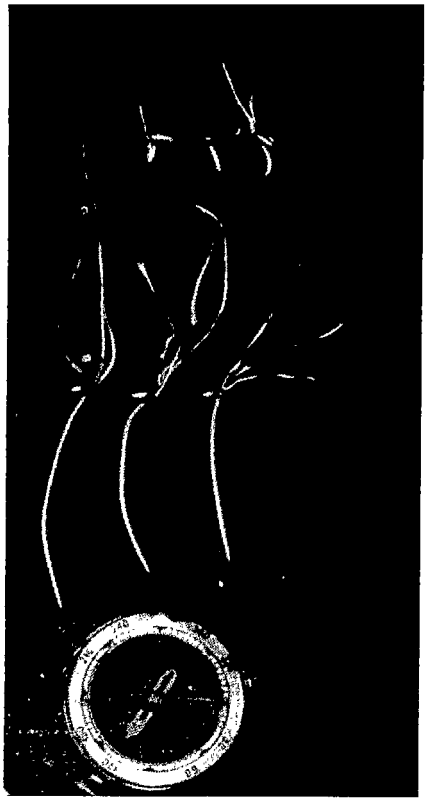


FIGURE 5. Influence of the geomagnetic field on the effect of gibberellin upon germination of the wheat variety "Krasnozernaya;" above-seeds arranged with their radicles toward the North Pole; below-toward the South Pole.

Initial studies of magnetotropism, and, in this connection, of polarity as an electric and magnetic characteristic of the living system, indicate the possibility of revealing important patterns in the life activities of plants. Successful research in this field will make possible a new approach to the study of the most important aspects in the life activities of organisms.

We shall briefly analyze some results of our studies on the effect of the magnetic field on the germination of various seeds.

We studied polarity further by recording the simultaneous effect of the magnetic field and of physiologically active substances. Gibberllin was selected as a suitable substance. An aqueous solution of gibberellin, in a concentration of 10^{-6}, was introduced through a capillary tube into the endosperin of the wheat variety "Krasnozernaya." The seeds had been oriented to the corresponding poles of the magnet prior to their injection. The effect of gibberellin was found to differ according to the orientation of the seeds. The growth-promoting effect of gibberellin on seeds with radicles directed toward the North Pole of the magnet was stronger than on those with radicles oriented toward the South Pole. Our findings indicate that the same substance produces different effects for different polarities (Figure 5).

Interesting observations were made concerning the susceptibility to mod fungi of germinating seeds with different orientations in the magnetic field. The seeds oriented with their radilces to the North Magnetic Pole were more readily attacked by molds than those oriented toward the South Magnetic Pole. This indicates that the polarity significantly affects the interrelationships between plants and microorganisms.

The above facts indicate that changes in the electric and magnetic properties of a living system caused by various factors are reflected in the diverse processes associated with the life activities of the organisms. A more thorough and comprehensive study of these phenomena should prove to be of considerable practical importance.

CONCLUSIONS

1. It was established that the geomagnetic field definitely affects growth processes in plants.

2. It was shown that the effects of magnetic fields, both of the Earth and of permanent magnets, on the life activities of sprouts was most pronounced when the seeds— in dry state— were oriented with their radicles toward the magnetic poles.

3. A new phenomenon was discovered and designated magnetotropism; it involves oriented growth of roots in the direction of the Earth's South Magnetic Pole of artificial magnets. It was shown that magnetotropism is accompanied with changes in the rhythm of growth of both root and stalk. The growth of both was enhanced in sprouts from seeds whose radicles were oriented toward the South Magnetic Pole, and weakened when oriented in the opposite direction.

4. The phenomenon of magnetotropism suggests that polarity, which is a fundamental property of living matter, derives from the magnetic properties of substances.

5. It was established that gibberellin acts on germinating seeds according to the orientation of the radicles with respect to the magnetic poles.

6. The state of polarity is manifested by the differences in susceptibility of the sprouts to fungal infections. In this connection polarity assumes considerable importance in the interrelationships between plants and microorganisms.

7. Further studies of magnetotropism and polarity will make possible a new approach to biological investigations, and to the elaboration of methods designed to regulate the life activities of organisms.

REFERENCES

Publications in Russian

1. DORFMAN, Ya. G. Magnitnye svoistva i stroenie veshchestva (Magnetic Properties and Structure of Matter). — Gostekhizdat. 1955.
2. KRYLOV, A. V. and G. A. TARAKANOVA. Yavlenie magnitotropizma u rastenii i ego priroda (Magnetotropism in Plants and Its Nature). — Fiziologiya Rastenii, 7, No. 2, pp. 191–197. 1960.

Publications in Other Languages

3. AUDUS, L. I. Magnetotropism: a New Plant Growth Response. — Nature, 4707, pp. 132–134. 1960.

PART SIX
HISTORY OF SCIENCE

A.L. Chizhevskii

K.E. TSIOLKOVSKII'S WORLD PRIORITY

My friendship with K. E. Tsiolkovskii began in 1914 and continued until his death. I have kept his notes, letters, and photographs.

I will describe our struggle for Tsiolkovskii's priority in the field of astronautics and rocket dynamics. The reader will wonder why such a struggle should have occurred, since Tsiolkovskii has long been recognized throughout the world. However, in his day the situation was much more complex. Tsiolkovskii was scarcely known outside Russia, while in Russia itself rocket dynamics and astronautics were regarded as unimportant, unnecessary, and even undesirable because they might detract effort from the successful flying machines produced in Russia.

There are days in a man's life which influence entire months and years, and sometimes one returns to such days after many years. The second of October 1923 was one such day. It was a very ordinary day in late autumn — one on which the sky is overcast, and the trees almost bare, their fallen leaves rustling in the wind. When one is young, all days are beautiful and even the calm days of late autumn possess a charm of their own. The mind contemplates a myriad of wonderful things, and one feels the surge of some obscure but exhilarating strength, creative inspiration, and bustling activity.

It was on just such a day that I rose early and unfolded the newspaper "Izvestiya" (No. 223 of 2 October 1923) which had just been delivered. At the bottom of page four in the section "News of Science and Engineering" I read the following item:

"Can this be true? Surely this is Utopia!

"In his book 'Die Rakete zu den Planetenräumen' published in Munich Professor Hermann Oberth presents rigorous mathematical and physical proof that our modern engineering means are sufficient for attaining escape velocities and overcoming the force of terrestrial gravity. Astronomy Professor Max Wolf described Oberth's calculations as 'scientifically flawless.' The ideas expounded in the book coincide with the experiments of the American professor Goddard who recently proposed a sensational plan of sending a rocket to the Moon. The ample means available to the American scientist enabled him to embark on most important experiments, while Oberth's book provides them with a solid theoretical foundation.

"Oberth presents detailed descriptions of the machinery and apparatus capable of overcoming the Earth's gravity; furthermore, he proves that the human organism is capable of surviving a trip to the planets, and that the spaceship can also return to Earth.

"The author also discusses the profitability (!) of such an enterprise. The cost of the machine was calculated at one million gold marks. The practical-minded Germans think that a rocket flight to the Moon is hardly worthwhile. It is much more important that such rockets be put into orbit around the Earth, becoming miniature moons in themselves that can be used as observation stations, for signaling to all parts of the Earth by means of mirrors, for exploring still undiscovered countries, etc. They also have not ignored the strategic value of such artificial moons...

"The author imagines a trip to the Moon and back as follows: the rocket is connected to a sphere filled with fuel. Upon arrival at the destination the rocket is detached from the sphere and lands, while the sphere continues to revolve around the planet; when the time comes for the return trip to Earth the rocket is again connected to the sphere."

I read this item with bated breath. What about Tsiolkovskii? Why are Oberth and Goddard given precedence? Where is our Soviet priority? In short, I asked myself a thousand "why's," but could not anser a single one. Does the author of this newspaper article know about Tsiolkovskii? Is Tsiolkovskii known to the editorial board? I rushed to my bookshelves and took out a thick volume of the journal "Novosti Nauki" ["Science News"] for the year 1903 — a single copy which I had found way back in 1915 or 1916 in a second-hand bookshop in Moscow, after a prolonged search. Tsiolkovskii's article was clearly entitled "Exploration of Interplanetary Space with Reaction Vehicles."

Why, then, did they neglect Russian priority in this remarkable field — a priority dating back to 1903, i.e., twenty years earlier? All these questions were burning to be answered. There could not be even an hour's delay because work on interplanetary travel was already under way both in America and in Germany. This, at least, was my impression at that moment. I telephoned the editorial office of "Izvestiya," and finally succeeded in reaching the Science and Engineering section.

"Did you publish an article about a flight to the Moon?" I asked.

"Yes, we did."

"But don't you know that in our country Tsiolkovskii has been working on this for thirty years?"

"Sorry, who did you say?"

"Tsiolkovskii!"

"But that's Utopia... The editorial board does not believe in his project. It is interesting but improbable."

"I can bring you a long article by Tsiolkovskii on this subject published in 1903 — I have it!"

"What is the title?" I was asked.

"It is entitled 'Exploration of Interplanetary Space with Reaction Vehicles'!"

"It is strange that the editorial board knows nothing about this subject. Incidentally, is it true that Tsiolkovskii is dead?"

"No, he is alive and well. He lives in the town of Kaluga and is continuing his research on this subject."

"All right. Thanks for the information. We shall consult some aviation experts. We are connected with some prominent scientists. They will answer our inquiry. Contact us in two or three days."

Three days later I again called the editorial office and spoke to the same worker (F. Kapelyush). He said—

"Yes, yes! The editorial office has made inquiries in aviation circles. The most prominent experts think that rockets are absurd, and that the proposals of the German and American scientists are of no practical interest. In other words, they are Utopian, just as we stated in our article."

"Just a moment," I interrupted, "Tsiolkovskii's work was substantiated many years ago... and therefore the priority is his..."

"Priorities in Utopian writings," interrupted Kapelyush in his turn, "are of no interest to science, and therefore our newspaper finds no need to deal with this affair. The item that was published should be regarded as one of those 'scientific curiosities' with which the bourgeois scientists amuse themselves! Remember Cyrano de Bergerac or Jules Verne! Flights to the Moon— these are all old fantasies!"

It was quite clear to me that I could not count on the newspaper to restore Russian priority in this field. At that time Tsiolkovskii's idea was not embraced by anyone because it was years ahead of itself! Many aviation theoreticians were unable to visualize the engineering possibilities of the approaching decades. Yet, these possibilities were envisaged by Tsiolkovskii with the penetrating eye of his genius, and by those who possessed imagination— imagination without blinkers— imagination of people who are not tempted to kneel before contemporary idols, but who look far into the future with their eagle eyes.

When Professor Oberth's book "Die Rakete zu den Planetenräumen" ("The Rocket into Interplanetary Space") was published in 1923 nobody was concerned with restoring Tsiolkovskii's priority. Even engineers who were beginning to have some glimmer of rocket dynamics did not move a finger in defense of the priority of our own scientist Tsiolkovskii. The unanimous opinion in engineering circles was that Prof. Oberth was a real scientist who was engaged in intensive studies of the problem of jet propulsion, whereas Tsiolkovskii was only a self-taught amateur who had closely approached the subject, but who certainly could not compete with a European scientist. This utterly fallacious concept was based on a long-standing tradition, very tenacious, but unpatriotic and contemptible; it stated that everything that was made in Russia was bad while everything foreign was good! ... This deeply rooted prejudice also governed the attitude toward Tsiolkovskii's work— patronizing and supercilious. There were certainly people who were of a different opinion, mainly young people. If I am not mistaken, the appearance in newspapers of an article "Is this Utopia?" was followed by an article in defense of Tsiolkovskii's priority published by "The Association of Naturalists" inspired by engineer Kazhinskii, a man of progressive ideas. However, his was a voice in the wilderness, and this isolated article could not influence world opinion. Bracing myself I telephoned many prominent aviation experts. These telephone interviews left me with a feeling of complete isolation. Nobody paid any attention to the newspaper article nor to rocket dynamics itself. One of the experts answered by query as follows:

"All this is nonsense— it is not worth talking about. Let these dreamers write. It has nothing to do with science."

I was stunned by such conservatism and the apparently total lack of comprehension. Nobody was concerned with jet propulsion. Together with a few other enthusiasts, I considered Tsiolkovskii's work remarkable and completely convincing; I could not grasp this total rejection of his work. Therefore I undertook the difficult task of reclaiming the true priority for Tsiolkovskii.

Nothing was done in defense of his priority, even by the few people who actually regarded themselves, and really were, his personal disciples. Furthermore, they did not grasp the essence of the entire issue, namely that Tsiolkovskii's complete works inaugurated a new scientific era— the era of interplanetary space! This idea was beyong their comprehension! They regarded Tsiolkovskii as an engineering amateur at best, but in no way as the founder of a new trend in world science in general.

Some people said:

"Tsiolkovskii has nothing to do with this. His writings are no more than 'rough drafts', glittering generalities; no precision, no experiment; many others wrote on the same subject and in the same manner long before Tsiolkovskii. Tsiolkovskii can lay no claims to priority..."

These people were quite ready to deny Tsiolkovskii the priority in favor of Esnault-Pelterie, Jules Verne, or Cyrano de Bergerac, yet they knew very well that Tsiolkovskii alone had provided the first valid foundation for rocket dynamics and astronautics. They were ready to recognize the priority of Goddard or Oberth but not that of Tsiolkovskii. These tendencies were obvious; considerable energy was needed to defend Russian priority in rocket dynamics and astronautics in face of the entire world despite any obstacles.

In the first place I had to make a preliminary study of Oberth's book to see how close his ideas were to Tsiolkovskii's. Once Tsiolkovskii had told me in the course of a conversation, "In the hands of a capable engineer the rocket may become a powerful weapon, with a range thousands of times longer than that of any artillery gun." Consequently one had to act with circumspection. I decided to find Oberth's book; I went to the editorial office of the newspaper "Izvestiya" and was referred to several people. It was only after several days that I succeeded in tracing the book I sought. Only ten or fifteen minutes after getting the book into my hands I was able to see that his arguments proceeded along the same path as those of Tsiolkovskii; the basic results of the two authors were identical, and therefore there was no further need to maintain the "secrecy" of Tsiolkovskii's work. Immediate action was needed to restore the Russian priority in rocket dynamics.

On the following day I set out for Kaluga. After a discussion with Tsiolkovskii we decided to act with determination in defense of his priority. On the following morning the two of us visited the head of the Kaluga Provincial Department of Education, N. N. Kostromin, who received us immediately, listened to us attentively, and agreed with our arguments. He immediately called M. P. Abarshalin at the printing office and reached an agreement concerning the printing of Tsiolkovskii's book.

Kostromin was a progressive person and understood that priority in the theory of rocket flight might have been unjustly claimed by someone abroad and that it would then be difficult to rightfully restore the priority to the Russians. However, the printing office did not have any reserve paper; we had to find the paper ourselves.

FIGURE 1. K. E. Tsiolkovskii's portrait presented by him to A. L. Chizhevskii. Published for the first time. [The Russian inscription reads: "To esteemed Aleksandr Leonidovich Chizhevskii. This is my photograph at the age of 75, 3 July 1934, Kaluga, 1, Tsiolkovskii Street, K. Tsiolkovskii."]

Kostromin advised me that the paper could be obtained at the Kondrovo paper mill. He gave me a letter in the name of the provincial education department but advised me to deliver the letter personally.

The Kondrovo paper mill (it had once belonged to the Goncharovs and had been visited by A. S. Pushkin [the famous Russian poet] while he was engaged to Natalia Nikolaevna Gonchareva) is situated 40 km from Kaluga.

I started out for the paper mill on the following day and stayed with the Gribanovs who resided at the mill. (I happened to know Madame T. D. Gribanova from Kaluga.)

However it was not so easy to get the paper. Having learned that I was a scientific worker, the factory manager A. V. Kaiyats requested me to deliver several lectures to the factory workers— for the paper. I agreed, and delivered a short series of lectures on the then modern achievements in physiology and medicine. The factory workers liked my lectures, and the necessary quantity of paper was supplied. A few small paper rolls were loaded on a low wide sledge and we trudged back to Kaluga over a snow-covered country lane. We reached the printing office toward evening and delivered the paper to their warehouse. The first part of the work was done.

At the same time my father L. V. Chizhevskii was busy translating Tsiolkovskii's book into German (so as not to lose time), and Tsiolkovskii himself was writing an introductory chapter to his new book.

On the day following the delivery of paper I went to the printing office for the final arrangements about the typesetting of Tsiolkovskii's book. It was decided that the title should be "Rocket to Interplanetary Space," similar to Oberth's pamphlet. After a prolonged search for some German (Latin) type we had not found enough to set a booklet of two printer's sheets. Apparently, most of the Latin type in that printing office had been lost during the years of Revolution. The available amount of German type was only sufficient to set my preface. We decided that once the German preface was read, the book would be translated abroad, the subject being very topical. There were plenty of Russian translators in Germany.

Tsiolkovskii's book was ready at the printing office on the mournful day of Lenin's death, 21 January 1924. Red flags with black borders flew over all the houses of Kaluga while I was walking to the printing office to deliver the book. The frost was severe and my steps rang on the streets. The office was also in mourning. It was only a few days later that I received the books. Some copies were delivered to Tsiolkovskii, and I took about 300 copies and set off for Moscow. I found the necessary European and American addresses, and in the course of a few days sent about 250 copies to approximately ten countries. to the best-known institutions, libraries, and to many scientists who in my opinion would definitely be interested in Tsiolkovskii's works. Ten copies each were sent to Professors Oberth and Goddard. Thus, the task was completed, the duty fulfilled, and the only thing left to us was to sit and wait for the response. I also distributed Tsiolkovskii's book to many Soviet specialists. The return address on the parcels containing the books was that of Tsiolkovskii, namely Kaluga, 3 Jaurès Street.

Prof. Oberth's first assistant was engineer A. B. Szerszewski, a Pole by nationality. When Tsiokovskii's book with the German preface reached Oberth he asked Szerszewski for a translation. A few months after that

Tsiolkovskii received a friendly letter from Szerszewski, which initiated a correspondence between the two. In one of his letters, Szerszewski asked Tsiolkovskii to give me his collegial regards as Tsiolkovskii's "assistant." In this connection Tsiolkovskii wrote to me from Kaluga to Moscow as follows:

"Dear Aleksandr Leonidovich [Chizhevskii],

I would have sent you the booklet long ago if I had only known your precise address. I was not even sure whether you were in Moscow. Nevertheless I am sending the booklet at random. You had better come and see me. Szerszewski (from Berlin) sends you his collegial greetings as my 'assistant'. Probably you were 'promoted' to this status because of your German preface. You should always mark your address on your letters. As soon as I have received your address I will send you a few copies of the booklet. You will take more copies when you visit me at Kaluga. I am ill but working.

Yours,
K. Tsiolkovskii."

Szerszewski to Tsiolkovskii:

"The rocket is our future. You probably know of Oberth's and Goddard's rockets. They want to send a small rocket to the Moon. You see that in this way your dream and that of other great people of vision for the future will be fulfilled much earlier than the previously assumed 100 or 1000 years... and I hope that you, as the prophet of interplanetary flights, will live to see the red-letter day of the first flight to the stars. The priority is undoubtedly yours (this fact I am pointing out to everybody, untiringly), and therefore it is your sacred duty, as well as that of your government, to start on practical work..."

Prof. H. Oberth to Tsiolkovskii:

"Esteemed Colleague,

Thank you very much for the MS material received from you. I should be the last man to deny your priority and your achievements in the field of rockets. I only regret that I did not hear of you before 1925 (this is an error; it should read '1924.' — A. Ch.). In that case I should have certainly advanced much further than I have up to now and would have avoided many unnecessary mistakes, if I could have known of your excellent work."

In another letter, Oberth wrote as follows:
"You ignited the flame and we will not let it be extinguished, but will make every effort to realize mankind's greatest dream."

Szerszewski wrote:*

"The senior Russian scientist K. E. Tsiolkovskii was the first to treat the problem of the spaceship scientifically. His first work on this subjet appeared in 1903, and it was republished in 1924. The continuation of the 1903 work was published in 1911–1913 in the Russian journal 'Vestnik Vozdukhoplavaniya' which was the first specialized journal

* Luftfahrt-technische Nachrichten, Berlin. 1924 -26.

in the world to publish a classical solution of the problem of interplanetary rockets. In this work theory overtook practice. In his preface to the 1924 edition, the young scientist Chizhevskii reviews Tsiolkovskii's works on rockets, emphasizes his scientific priority, and complains about the almost criminal indifference to scientists on the part of the general public."

It is already 39 years since the publication of Tsiolkovskii's booklet "Rocket to Interplanetary Space." This is a long time not only in the life of an individual but also of an entire society. The world has changed beyond recognition in many respects, there have been tremendous changes in social structure and prospects, and therefore it is now very interesting to see how people regard those distant years. Such interest is quite justified.

A new basic book on astronautics was published at Constance in 1958, edited by the Munich Professor Karl Schütte. It contains a paper "History of Interplanetary Travel" by Willy Ley. This is how Tsiolkovskii's role and the significance of the 1924 edition of his booklet are regarded by the contemporary German historian of this subject:

"A turning point in Tsiolkovskii's life occurred after the publication of Hermann Oberth's book 'Die Rakete zu den Planetenraumen' in 1923. The German book was discussed in the Russian press and Tsiolkovskii's original work of 1903 was immediately republished as a booklet, under the new title 'Rocket to Interplanetary Space'."

Thus, Ley's paper provides objective proof of the importance of the prompt republication of Tsiolkovskii's work in 1924.

In conclusion it should be said that during the last years of Tsiolkovskii's life his work was duly recognized in the USSR. At the present time, the name Tsiolkovskii enjoys world-wide renown and respect.

EXPLANATORY LIST OF ABBREVIATIONS OF USSR PERIODICALS AND INSTITUTIONS APPEARING IN THIS TEXT

Abbreviation	Full name (transliterated)	Translation
DAN SSSR	Doklady Akademii Nauk SSSR	Reports of the Academy of Sciences of the USSR
GAISh	Gosudarstvennyi Astronomicheskii Institut imeni P. K. Shternberga	State Institute of Astronomy im. Shternberg
GGI	Gosudarstvennyi Gidrologicheskii Institut	State Hydrological Institute
GUGK	Glavnoe Upravlenie Geodezii i Kartografii	Main Administration of Geodesy and Cartography
LGU	Leningradskii Gosudarstvennyi Universitet	Leningrad State University
MIIGAiK	Moskovskii Institut Inzhenerov Geodezii, Aerofotos"emki i Kartografii	Moscow Institute of Engineers for Geodesy, Aerial Photography and Cartography
MGU	Moskovskii Gosudarstvennyi Universitet	Moscow State University
MVTU	Moskovskoe Vysshee Tekhnicheskoe Uchilishche (im. N. E. Baumana)	Moscow Higher Technical School (im. N. E. Bauman)
OIYa	Ob"edinennyi Institut Yadernykh Issledovanii	Joint Institute of Nuclear Research
SNK	Sovet Narodnykh Komissarov	Council of the People's Commissars
TsNIIGAiK	Tsentral'nyi Nauchno-Issledovatel'skii Institut Geodezii, Aeros"emki i Kartografii	Central Scientific Research Institute of Geodesy, Aerial Surveying and Cartography
TsNILI	Tsentral'naya Nauchno-Issledovatel'skaya Laboratoriya Ionizatsii	Central Research Laboratory of Ionization
UFN	Uspekhi Fizicheskikh Nauk	Advances in Physical Sciences
VAGT	Vsesoyuznyi Aerologicheskii Trest	All-Union Aerological Trust
VGO	Vsesoyuznoe Geograficheskoe Obshchestvo	All-Union Geographical Society
VNII	Vsesoyuznyi Nauchno-Issledovatel'skii Institut	All-Union Scientific Research Institute
VSEGEI	Vsesoyuznyi Nauchno-Issledovatel'skii Geologicheskii Institut	All-Union Scientific Research Geological Institute

National Aeronautics and Space Administration
WASHINGTON, D. C. 20546

OFFICIAL BUSINESS

POSTAGE AND FEES PAID
NATIONAL AERONAUTICS AND
SPACE ADMINISTRATION

[illegible] 0903
[illegible] LABORATORY/AFSC/
[illegible] AIR FORCE BASE, NEW MEXICO 87117

[illegible] ACTING CHIEF TECH. LIBRARY

Cover printed in Jerusalem, Israel

NASA TT F-345
TT 66-51025